Water Resource Report 28

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Hydrology of the Pleistocene Sediments in the Wyoming Valley, Luzerne County, Pennsylvania

Jerrald R. Hollowell

COMMONWEALTH OF PENNSYLVANIA
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Arthur A. Socolow, State Geologist

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Hydrology of the Pleistocene Sediments in the Wyoming Valley, Luzerne County, Pennsylvania

by Jerrald R. Hollowell
U. S. Geological Survey

Prepared by the United States Geological Survey, Water Resources Division, in cooperation with The Pennsylvania Geological Survey

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PREFACE

The Wyoming Valley is an area completely underlain by glacial deposits. Beneath the glacial overburden vast-mine workings honeycomb coal beds of the Northern Anthracite Field. Beginning in 1959 these mines became filled with water as they were abandoned.

This report was written to provide information for those seeking water or indirectly concerned with ground-water conditions affecting building construction and excavation. The report provides information on the depth, availability, quantity, and quality of water that may be obtained from the glacial deposits. The interrelation of mine water with the ground water in the glacial overburden is of major importance to development of the glacial overburden for water supplies. Nine million gallons per day of fresh water is available to water supply wells without inducing additional recharge from the river or mines. Over 700 million gallons per day of additional water can be induced from the Susquehanna River by production wells placed near the river.

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Hydrology of the Pleistocene Sediments in the Wyoming Valley, Luzerne County, Pennsylvania

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ABSTRACT

Thick accumulations of glacial till, outwash deposits, and lake deposits underlie the Wyoming Valley in Luzerne County, Pa. Most till and outwash deposits occur as isolated remnants above the river flood plain. Because they lie mostly above the water table, these deposits contain very little water and are not known to yield water to wells.

The lake deposits occupy a part of the valley that was deepened by glacial action to more than 300 feet below the present river flood plain. They consist of beds of clay, sand, and sand and gravel deposited by the glacial streams flowing into the lake. Deltas of sand and gravel were formed at the mouths of the streams, and beds of clay were formed in still areas of the lake. Outwash deposits of sand and gravel overlying the lake deposits were left by later Pleistocene floods. Yields of as much as 1,200 gpm (gallons per minute) have been reported from wells tapping the sand and gravel.

The bedrock that underlies the glacial deposits and forms the sides of the valley is comprised of well-indurated, thin- to massive-bedded sandstone, conglomerate, shale, and siltstone of Mississippian and Pennsylvania age. Seams of anthracite coal ranging from a fraction of an inch up to 27 feet in thickness occur in the bedrock. Mining of the anthracite beneath the Wyoming Valley has altered the natural sub-surface hydrologic system by creating large conduits that provide free movement of the ground water. When the mines became uneconomical to operate, they were abandoned and most of the underground cavities were subsequently filled with water.

The glacial deposits beneath the valley flood plain constitute the most important aquifer in the Wyoming Valley. The aquifer is used only for irrigation at present. Recharge to the aquifer, mainly from precipitation, is estimated to be 15 inches per year. At present recharge from the mines below is only a small fraction of the total recharge to the glacial deposits. Natural discharge from the glacial deposits is mainly by seepage into the streams. Seepage into the

mines is limited to those areas where the water level in the glacial deposits is higher than that in the mines below. Over 1 billion gpd (gallons per day) of ground water probably could be obtained by pumping wells placed near the river and inducing water into the aquifer from the Susquehanna River. The infiltration water would have a relatively constant temperature, quality, and quantity adequate for municipal or industrial use.

The ground water in the glacial deposits is predominantly of the calcium bicarbonate-sulfate type, high in dissolved solids, and hard. Locally, the quality is affected adversely by surface deposits of mine waste which contribute large quantities of leached calcium, iron, and sulfate ions to the ground water.

INTRODUCTION

PURPOSE AND SCOPE

The purpose of this report is to describe (1) the availability, occurrence, movement, and chemical quality of the water in the Pleistocene glacial sediments of the Wyoming Valley, (2) the relationship between the water in the sediments and that in the underlying and adjacent coal mines and (3) the relationship between the water in the sediments and that in the Susquehanna River and other surface water bodies flowing over the sediments.

Information concerning the availability and chemical quality of the water in the glacial deposits of the Wyoming Valley is extremely scarce, although wells are known to have yielded more than 1,000 gpm from the glacial deposits. The area is in the heart of the Northern Anthracite coal-mining field, and because of the vast extent of underground mining, the ground-water resources of the valley are essentially limited to the overlying glacial deposits.

This investigation was begun in 1964 as part of the continuing study of ground-water resources of Pennsylvania being made by the U.S. Geological Survey in cooperation with the Pennsylvania Topographic and Geologic Survey.

LOCATION AND EXTENT OF THE AREA

The Wyoming Valley lies along the Susquehanna River in central Luzerne County, in northeastern Pennsylvania (Fig. 1). It extends from Pittston to Nanticoke and is shown on the Wilkes-Barre East, Wilkes-Barre West, Kingston, Pittston, Nanticoke, and Avoca 7½-minute quadrangles. The valley is about 15 miles long and 5 miles wide at midvalley.

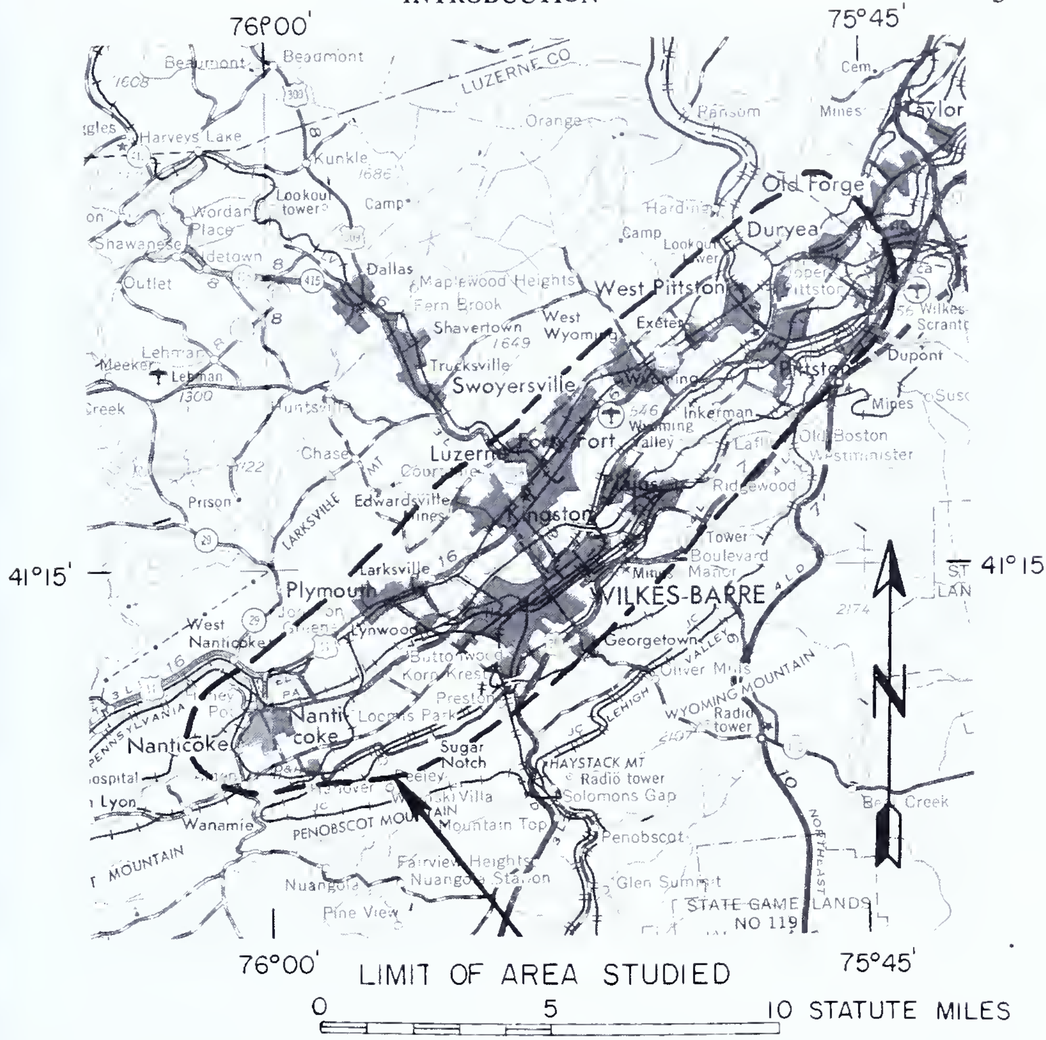

Figure 1. Map of the Wyoming Valley and its location in Pennsylvania.

PREVIOUS INVESTIGATIONS

Several earlier investigations of the geology and water resources of the area have proven helpful in the preparation of this report. The ground-water resources of Luzerne County are described briefly by Lohman (1937) who made a reconnaissance investigation of the ground-water resources of northeastern Pennsylvania. Itter (1938) interpreted the geomorphology of the Wyoming region. Peltier (1949) discussed the source and deposition of the Pleistocene river terraces of the Susquehanna River. The buried valley of the Susquehanna River in the Wyoming-Lackawanna Valley is described by Ash (1950). The barrier pillars between underground mines in the Wyoming basin are described by Ash (1954).

A major part of the geologic map accompanying this report is from the unpublished work of M. J. Bergin and J. F. Robertson, U.S. Geological Survey, prepared in 1964, for a preliminary report to the Corps of Engineers on the geology of the Wyoming Valley.

METHODS OF INVESTIGATION

Information on well depth, depth to water, and yield of wells was obtained from well owners and by field measurements. Additional hydrologic data were obtained by drilling 12 observation wells into the glacial deposits. Aquifer tests were made at four locations to determine transmissibility and storage coefficients of the glacial deposits. All observation wells and selected privately owned wells were measured periodically. Continuous water-level records were obtained on five wells. Water samples for chemical analyses were collected from 10 wells and 1 mine shaft. The analyses were made in the U.S. Geological Survey laboratory located in Philadelphia, Pa.

Logs of approximately 500 holes, selected from logs of 12,000 or more test holes drilled in the Wyoming Valley by local coal companies, were plotted at a compilation scale of 1-inch equals 500 feet, for study of the glacial sediments. Lithofacies maps, at the scale of 1-inch equals 2,000 feet, were constructed from these logs.

WELL-NUMBERING SYSTEM

All wells inventoried have an identification number and a location number. The identification number is used for easy reference to a well during discussion and consists of two parts. The first part is a two-letter symbol that identifies the county in which the well is located, for example, Lu for Luzerne County. The second part of the identification number is a serial number assigned at the time the well is inventoried.

The location number is for the purpose of identifying the geographic (or map) location of a well, and it is the coordinates of a point on a map scaled to within a second of latitude and longitude (see sketch A, Figure 2). The well will always be to the north and west of the geographic point designated by the well number (see sketch B, Figure 2). The numeral after the decimal is the sequential number of the well located in the 1-second quadrangle designated by the latitude and longitude (see sketch B, Figure 2).

IDENTIFICATION OF DRILL HOLES

Logs of holes drilled by mining companies are identified only by the number assigned by the mining company. The logs are shown in numerical order for each mine property.

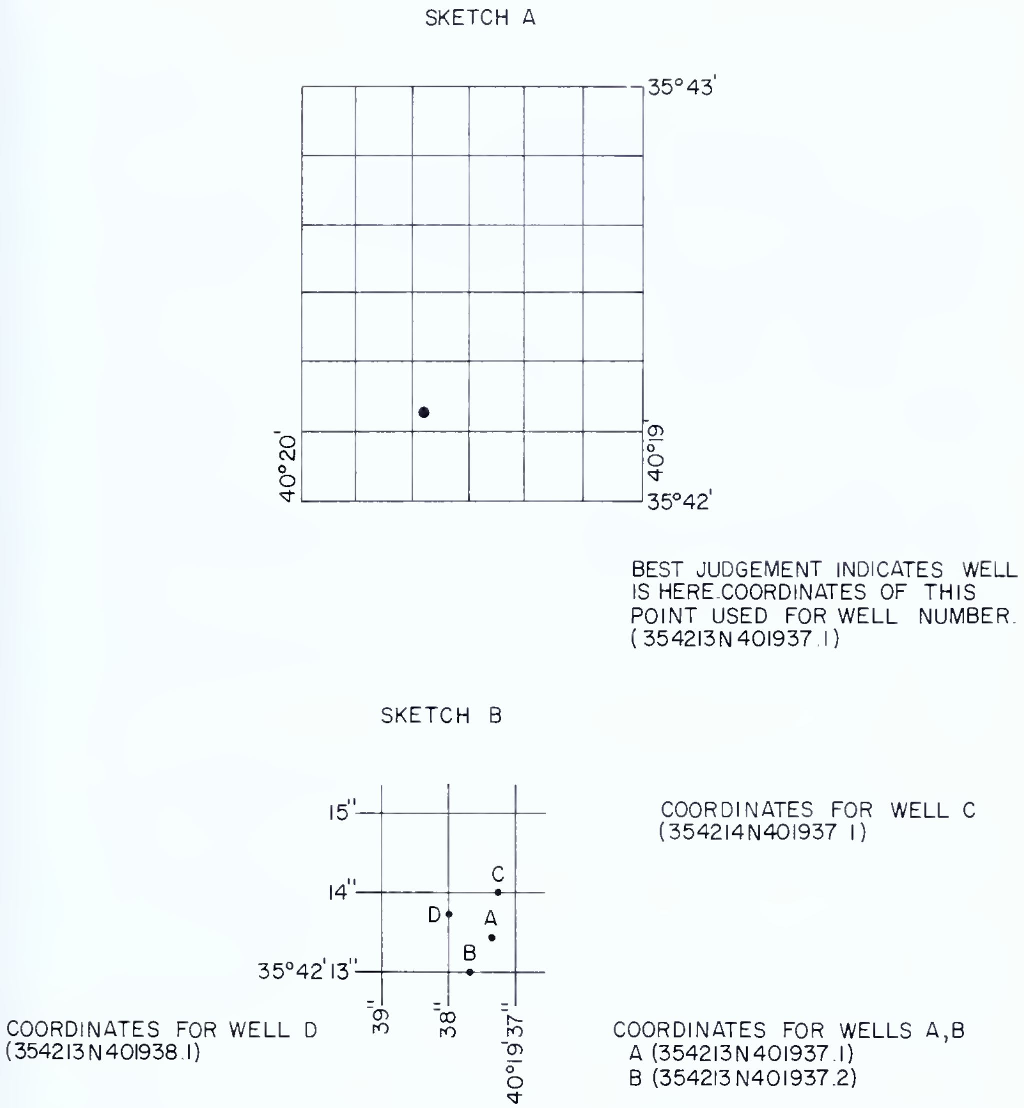

Figure 2. Sketches showing the system used for locating wells.

ACKNOWLEDGMENTS

The author gratefully acknowledges the cooperation and assistance of the individual landowners and well owners for providing information on wells, and for granting permission to drill observation wells and to conduct aquifer tests on their property. Particular thanks are due to Lesko Barney Corp., Kingston, Pa., for providing the equipment used for test pumping their wells.

Appreciation is expressed to the Pennsylvania Department of Environmental Resources, Division of Mines and Mineral Industries, Wilkes-Barre, who helped in obtaining elevations on mine openings where water-

level measurements were made; to the U.S. Bureau of Mines, Wilkes-Barre, for access to their field and mine maps; and to Wilbur T. Stuart, formerly of the U.S. Geological Survey, who made available data on mine-water pools and provided helpful suggestions.

Mr. M. J. Bergin and J. F. Robertson, U.S. Geological Survey, provided the thousands of drill-hole logs they collected from the files of coal-mining companies and the base map showing the drill-hole locations compiled from the original mine maps.

The following mining companies are acknowledged for releasing the drill-hole logs for publication in this report: Blue Coal Corp., Ashley, Pa.; Pagnotti Coal Co., West Pittston, Pa.; and Pennsylvania Coal Co., Scranton, Pa.

Mr. Roy Thomas of Albright and Friel, Inc., provided altitudes, on the U.S. Coast and Geodetic Survey base, of the bench marks he established in the Wyoming Valley.

Acknowledgment is made also to William C. Roth, U.S. Geological Survey, who helped in field leveling and in collecting hydrologic data.

GEOGRAPHY

SURFACE FEATURES AND DRAINAGE

The Wyoming Valley is the southern half of a long valley rimmed by two pairs of mountain ridges. The valley resembles a crescent-shaped dish that has a high outer rim and a lower inner rim. The valley and adjacent ridges are a part of the Appalachian Mountain Section of the Valley and Ridge Province (Fig. 3).

The northern half of the valley, known as the Lackawanna Valley, is separated from the Wyoming Valley at the point where the Lackawanna River enters the Susquehanna River. For the purposes of this report, however, the separation was made at the Luzerne-Lackawanna County line.

The relief within the Wyoming Valley from the flood plain of the Susquehanna River to the top of the inner ridge of the mountains is about 1,100 feet. The relief to the summit of the higher outer ridge is about 1,650 feet. The lowest elevation in the valley is 510 feet above mean sea level on the flood plain at the Nanticoke gap.

The Susquehanna River, the major stream in the region, enters the Wyoming Valley from the northwest through a gap in the mountains north of Pittston. The river flows generally southwestward over a wide alluvial plain for about 15 miles to where it turns west and flows through a gap in the rimming mountains near Nanticoke. The Lackawanna River,

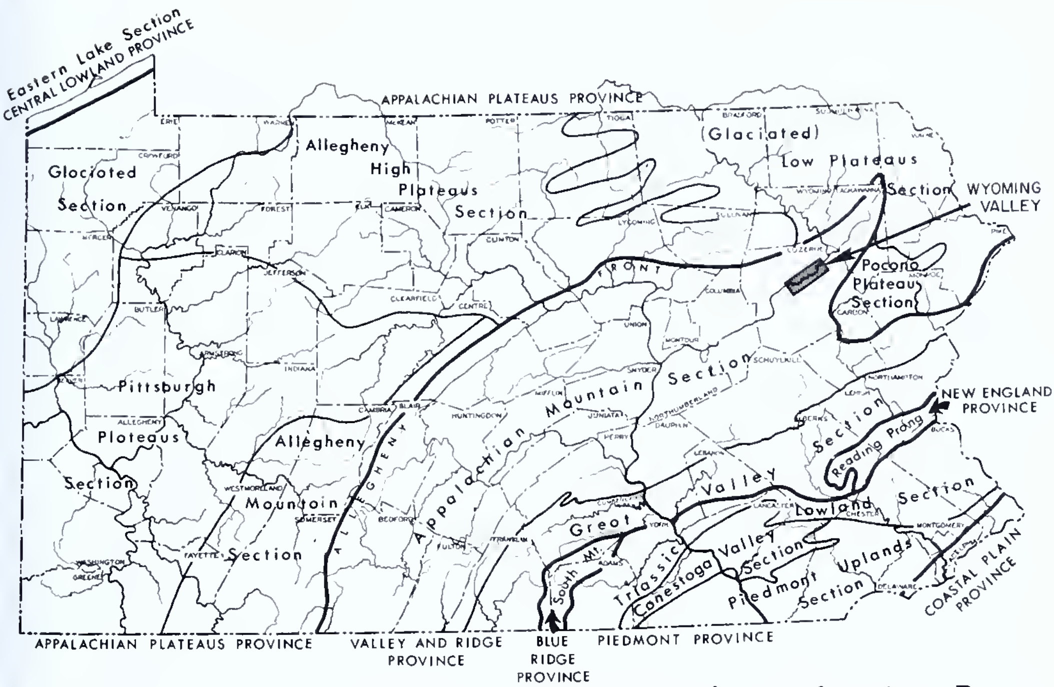

Figure 3. Map showing the physiographic provinces of eastern Pennsylvania and the location of the Wyoming Valley.

the second major stream in the valley, enters the Susquehanna River near Pittston (Fig. 1).

The dominant surface feature in the Wyoming Valley is the wide alluvial plain adjacent to the Susquehanna River into which the river has cut a series of low terraces. Outside the alluvial plain, gentle to moderately rolling land is formed on the upper terraces of the Wyoming Valley.

Many surface features in the Wyoming Valley are the result of anthracite mining. Waste rock, culm, and silt banks present huge masses of broken rock on which little or no vegetation takes root. Some of these banks are over 100 feet high and where they contain enough coal refuse, they may be burning. On the mountain slopes where the coalbeds come to the surface, "stripping" of the coal has resulted in a series of deep gashes with waste rock heaped to one side.

Surface subsidence is a less obvious but widespread effect of the underground mining. This occurs where all the coal in a seam was removed allowing the roof rock in the mine to cave. In some areas subsidence has resulted in a lowering of the land surface as much as 12 feet. Occasionally a deep "cave-in" occurs, where a small area on the surface suddenly drops down into the mine below. Surface subsidence has diminished now that most of the underground mining in the valley

has been discontinued and the mines have filled with water; however, subsidence often occurs during the filling of the mines.

Several new surface features are the result of the mines filling with water. North of the Lackawanna River near Duryea, a lake was formed at the elevation of the Seneca Pool. West of Duryea a permanent stream was created from a gravity overflow of 20,000 to 29,000 gpm.

The topography of the alluvial plain has been changed to a minor extent by mining of soil, sand, and gravel for construction and landscaping purposes.

CLIMATE

The climate of the Wyoming Valley is humid and characterized by warm summers and mild winters. The average annual precipitation is 38.75 inches, based upon 30 years of record at the Wilkes-Barre-Scranton Airport Weather Bureau (U.S. Department of Commerce, 1967). The precipitation is greatest during May-July and least during December-February (Fig. 4).

Snowfall in the valley has averaged 33 inches during the past 20 years of record. About two-thirds of winter precipitation in the valley occurs as rain.

The mean annual temperature recorded at the Wilkes-Barre-Scranton Airport Weather Bureau (U.S. Department of Commerce 1964) is 50° F. The mean monthly temperature ranges from a minimum of 26° F in January to a maximum of 72° F in July (Fig. 4). The average frost-free

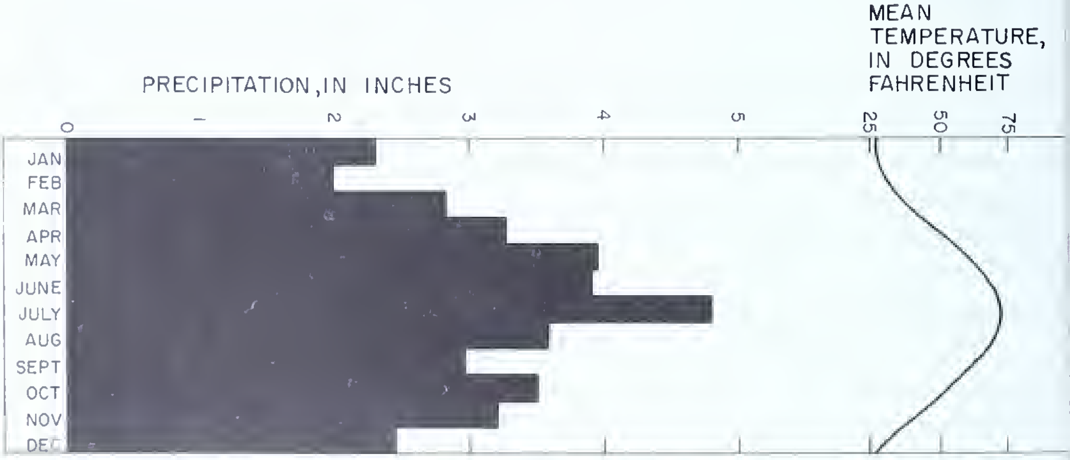

Figure 4. Graphs showing the normal-monthly precipitation and the mean monthly temperature at Wilkes-Barre - Scranton Airport.

period, based on 11 years of record for the valley, is 165 days between April 26 and October 8.

In an average year there are 68 clear (cloudless) days, 113 partly cloudy days, and 184 cloudy days. Heavy fog occurs about 27 times a year predominantly during the late fall and winter months.

POPULATION

The Wyoming Valley is densely populated; the many small cities, communities, and boroughs form a metropolis numbering 225,000 in the 1960 census (U.S. Department of Commerce, 1962). Wilkes-Barre is the largest city and the Luzerne County seat. The population has declined in the valley since 1930, reflecting the decline in its once largest industry, coal mining. The population declined 3 percent between 1930 and 1940; 13.4 percent between 1940 and 1950; and 13.4 percent between 1950 and 1960. Census data (Pennsylvania Department of Internal Affairs, 1961, p. 41) for municipalties and townships with a population of 2,500 or over are as follows:

Municipality	*Population*	*Municipality*	*Population*
Ashley Borough	4,258	Nanticoke	15,601
Avoca Borough	3,562	Pittston Borough	12,407
Dupont Borough	3,669	Pittston Township	2,992
Duryea Borough	5,626	Plains Township	10,995
Edwardsville Borough	5,711	Plymouth Borough	10,401
Exeter Borough	4,747	Plymouth Township	2,983
Forty Fort Borough	6,431	Swoyersville Borough	6,751
Hanover Township	12,781	West Pittston Borough	6,998
Jenkins Township	3,475	West Wyoming Borough	3,166
Kingston Borough	20,261	Wilkes-Barre	63,551
Larksville Borough	4,390	Wilkes-Barre Township	4,319
Luzerne Borough	5,118	Wyoming Borough	4,127

INDUSTRY, MINERAL RESOURCES, AND AGRICULTURE

The main industry in the Wyoming Valley is manufacturing. There are approximately 470 manufacturing establishments in the valley (Pennsylvania Department of Internal Affairs, 1961, p. 234). The major industries and estimated employment are: apparel and related products, 12,000; leather and leather products, 2,700; textile mill products, 2,100; and tobacco products, 3,260.

The mining of anthracite was the main industry in the valley prior to 1954. Total production (net tons) for Luzerne County has been rapidly decreasing as shown in the following table (Pennsylvania Department of Mines, 1966):

1924	34,711,150	1960	5,380,696
1930	27,456,102	1965	5,346,676
1940	22,672.016	1966	4,478,219
1950	17,112,757		

Since the inundation of the mines by the Susquehanna River in January 1959, only two principal coal producers have continued operations.

Fresh produce is the main agricultural product in the Wyoming Valley. The alluvial plain along the Susquehanna River is ideally suited for agriculture; however, the land available for cultivation is rapidly being taken from use because of expanding urbanization, mining of top soil, sand, gravel, and land made vulnerable to frequent flooding because of subsidence.

BEDROCK GEOLOGY

STRATIGRAPHY

The bedrock in the Wyoming Valley is made up of well-indurated thin- to massive-bedded sandstone, shale, siltstone, conglomerate, and coal. The bedrock exposed along the margin of the valley consists of the following formations, from the oldest to the youngest: The Pocono Formation of Early Mississippian age, Mauch Chunk Formation of Mississippian and Pennsylvanian (?) age, and the Pottsville and Llewellyn Formations of Pennsylvanian age. Only the Llewellyn is delineated on the geologic map; the other formations are grouped as pre-Llewellyn (Plate 1). Their geomorphic and stratigraphic relationships are shown in Figure 5.

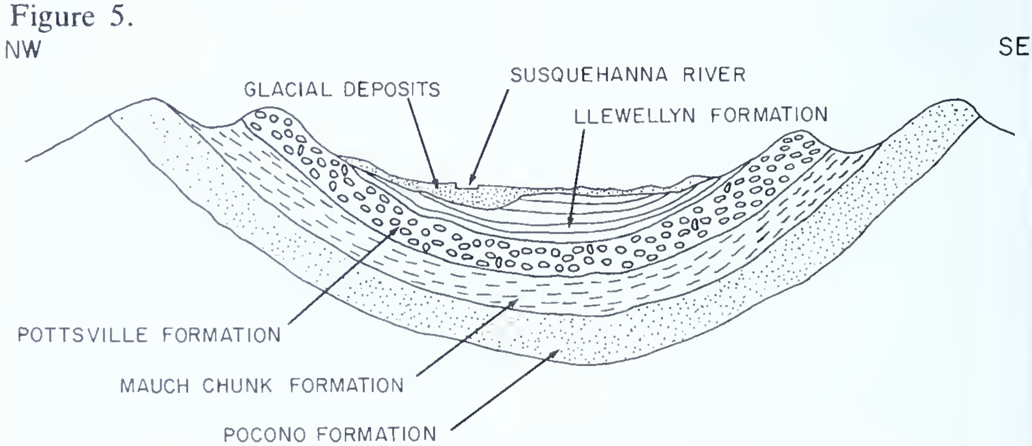

Figure 5. Generalized section through the Wyoming Valley synclinorium showing the relations of Mississippian and younger age rocks.

Pre-Llewellyn Formations

Three pre-Llewellyn formations crop out on either side of the valley. The Pocono Formation, about 600 feet thick, forms the outer ridge and is predominantly a gray, hard, massive, crossbedded conglomerate and sandstone interbedded with some siltstone and shale. The Mauch Chunk Formation thins northward and ranges in thickness from a few feet to about 1,000 feet and occupies the valley between the inner and outer ridges formed by the coarser grained rocks. It is predominantly a red shale interbedded with some brown and greenish-gray flaggy siltstone and sandstone. The Pottsville Formation, 200 to 300 feet thick, forms the inner ridge and is a light-gray to white coarse-grained sandstone and conglomerate.

Llewellyn Formation

The Llewellyn Formation underlies the Wyoming Valley and lower parts of the surrounding slopes. The formation is nearly 2,200 feet thick and is composed of interbedded light-gray, quartz-pebble conglomerate; light- to medium-gray, fine- to coarse-grained sandstone; light- to dark-gray shale and siltstone; medium-gray claystone; very dark-gray carbonaceous shale; and anthracite coalbeds.

The strata between the coalbeds commonly exhibit extreme lateral changes in thickness and lithology, and are characterized by crossbedding, truncated bedding, and channel deposits. The coalbeds are the most persistent strata and range in thickness from a fraction of an inch to 27 feet. At least 26 coalbeds are represented in the Llewellyn Formation (Ash, 1954). The lowest coalbed crops out on the mountain slopes on each side of the valley at an altitude of 1,000 to 1,100 feet.

The Llewellyn is covered with unconsolidated glacial deposits and exposures are scarce. It may be seen, however, in resistant ridges, where the glacial deposits have been removed by erosion, in roadcuts, and where excavation for coal has removed the surficial material.

STRUCTURE

The Wyoming Valley lies in the southern half of a large synclinorium whose axis trends about N 50° E and whose ends taper to points. The synclinorium is slightly crescent shaped in plan and is concave on the northwest side.

The rocks bordering the Wyoming Valley suggest a simple synclinal structure. However, the area is structurally anomalous to the Appala-

chians, and the rocks within the valley are complexly folded and faulted, and contain many subparallel anticlines and synclines and related faults. These features are discontinuous, and are seldom over a few miles in length. The deepest part of the synclinorium is about 1 mile east of Nanticoke. The trough becomes shallower toward its nose, about 9 miles southwest of Nanticoke, and toward a high point northeast of Pittston, immediately east of where the Lackawanna River flows into the Susquehanna River. This high point effectively culminates the Wyoming Valley and divides the synclinorium into two substructures. The second trough lies northeast of the Wyoming Valley in the general vicinity of Scranton, Pa., and is called the Lackawanna Valley.

Detailed discussion of the structure is beyond the scope of this report. However, further treatment of this subject may be found in Darton (1940).

GLACIAL GEOLOGY

ORIGIN OF THE BURIED VALLEY

The Wyoming Valley was invaded by glacial ice in the Illinoian time and again in Wisconsin time units of the Pleistocene glacial epoch. Evidence of the early glacial activity in the valley has been obliterated by the more recent glaciation (Itter, 1938, p. 19). During the greatest advances of the glaciers the ice crossed the Wyoming Valley and the mountains to the south. As the ice moved into the Wyoming Valley from the north it was turned westward by the mountains that flanked the valley on the south. All the ice within the valley flowed in a southwest direction parallel to the axis of the valley. The turning slowed the flow and caused the ice to pile up and increase in thickness over the valley. The increase in thickness added to its erosive powers, and the ice quarried hundreds of feet of rock from the valley (Itter, 1938, p. 67). The greatest excavations occurred in the Llewellyn Formation because the brittle anthracite beds in this formation were easily fractured and dislocated, facilitating the fracturing and removal of the adjacent beds.

This overdeepened part of the Wyoming Valley has since been filled with sediment and is locally referred to as the "buried valley." Coal companies operating mines beneath the buried valley have drilled thousands of boreholes through the sediments of the buried valley in order to define its depth and extent. The data acquired from the coal companies indicate the bedrock surface is very irregular, having as much as 300 feet of relief just south of the town of Plymouth (Plate 1).

GLACIAL DRIFT

The unconsolidated glacial deposits that overlie the bedrock in the Wyoming Valley are referred to generally as glacial drift. These sediments are composed of varying proportions of boulders, gravel, sand, silt, and clay. On the basis of their bedding, sorting, and topographic position the deposits are subdivided into unstratified and stratified drift. Areas shown on the geologic map (Plate 1) as undifferentiated glacial drift include those areas of ground moraine and glacial drift that have not been related to specific terrace levels or to other physiographic features typical of glaciated areas.

Unstratified Drift

Unstratified drift or till lacks bedding and is unsorted because it was deposited by the melting glacier ice with little or no transport by running water. The resulting deposits consist of a heterogeneous mass of clay, silt, sand, gravel, and boulders (Itter, 1938). In the Wyoming Valley, sand usually comprises most of the material in the unstratified sediments (Fig. 6). Till occurs only locally as a thin veneer in the Wyoming Valley. It is not shown as a distinct unit on the geologic map. (Plate 1) but is included with the undifferentiated glacial drift.

Figure 6. Photograph showing unstratified glacial till overlying a thin coalbed, 1 mile east of Pittston.

Stratified Drift

Stratified drift in the Wyoming Valley is classified as either proglacial sediments or ice contact sediments. The proglacial sediments are those that were deposited beyond the limits of the glacier as outwash sediments and lake sediments. The ice contact sediments were deposited as kame terraces in immediate contact with wasting ice. The ice contact and proglacial sediments may grade directly into one another; however, because of their topographic separation they will be discussed individually.

Kame terraces

Remnants of kame terraces occur on both sides of the Susquehanna River in the Wyoming Valley (Plate 1). The elevation of the upper surface is about 685 feet near Pittston and is about 10 feet less at the lower end of the valley (Itter, 1938). The terrace on the northwest side of the river is nearly continuous and can be traced from West Pittston to Plymouth. On the southeast side of the river it is discontinuous and poorly exposed. The kame terrace deposits range from 10 to 100 feet in thickness and consist of stratified sand and gravel, with a coarse gravel layer at the top. Locally, erratic boulders and pockets of till are incorporated within the deposits. The photographs in Figure 7 show both complex and simple structures. Deposition of these deposits are dincussed briefly in Itter (1938) and more fully in Flint (1957).

These kame terraces deposits are economically valuable as a sand and gravel source throughout northeastern Pennsylvania. In the Wyoming Valley they are mined nearly to depletion.

Lake sediments

Large scale maps made from logs of over 500 test borings in the overdeepened part of the Wyoming Valley show a distribution of coarse material and thick clay beds that indicate the sediments were deposited in a lake that stood at an elevation of about 560 feet. The deposits consist of deltas, moraines, bottom deposits, and rafted erratics, all of which are common in glacial lakes (Flint, 1957, p. 143).

Lithofacies maps of these sediments illustrate the character and areal complexity of the deposits (Plate 2). Each map represents an interval of sediments at different depths below land surface that illustrate the areal variations in the lithologic character of the unit mapped. Three intervals were selected: a 10 to 50 feet interval which consists mostly of coarse-grained sediments and is the interval in which most wells will be

A. Complex structure; 0.5 miles west of West Wyoming.

B. Simple structure; 0.25 miles northwest of Duryea.

Figure 7. Photographs showing kame-terrace deposits.

completed; a 50 to 100 feet interval which consists mostly of fine-grained sediments that retard vertical flow of ground water; and a 100 feet to bedrock interval which consists mostly of coarse sediments. The interval from land surface to 10 feet in depth was excluded because of poor well-log information.

These intervals were selected to establish a hydrogeologic framework and do not represent stratigraphic units. Further division of these sediments would have provided a useful, three dimensional picture of the lithology, however such detailed work was beyond the scope of this report.

Each map shows a composite of the material making up the interval. The grain size ratios mapped were determined by the following equation: (Krumbein and Sloss, 1951, p. 271).

$$\text{sand-clay ratio} = \frac{\text{thickness of sand and gravel beds in the interval}}{\text{thickness of clay and silt beds in the interval}}$$

There is a gradation in grain sizes between the coarse deltaic deposits and the finer lake deposits; however, the change is only shown in a general manner on Plate 2.

The lithofacies map for the 100 feet to bedrock interval shows predominantly coarse deposits. Some bottom deposits also are present; however, none of the finer bottom deposits exist at depths greater than 140 feet. Most of the deep coarse-grained sand and gravel material were probably transported into the trough by ice that occupied the overdeepened valley. Boulder erratics are common below 100 feet.

The lithofacies map for the 50 to 100 feet interval shows many small areas of coarse-grained deposits probably of deltaic origin, and an abundance of fine-grained bottom sediments. Some boulder erratics are contained in these sediments. End moraine sediments deposited when glacier ice occupied the center of the Wyoming Valley, make up much of the material downstream from Plymouth. This moraine probably was the dam that held the lake level about 60 feet.

The map of the 10 to 50 feet interval shows that coarse-grained deposits cover the fine-grained deposits below the junction of the Lackawanna and Susquehanna Rivers. This sequence of sediments indicates a gradual shoaling of the lake water and faster currents that had an increased capacity to carry suspended sediment downstream. The coarse-grained deposits are more extensive, and the fine-grained lake bottom deposits are coarser and less continuous than in the 50 to 100 feet interval. Some of the deposits were eroded away by later down-cutting by the river.

Sediment was transported from the melting ice to the glacial lake by

major streams entering from the Susquehanna River valley and the Lackawanna Valley, and by minor tributary streams along the sides of the Wyoming Valley. As the swift, sediment-laden streams entered the quiet water of the lake their velocity was greatly reduced. The reduction in velocity caused a reduction in their ability to carry sand and gravel, and these coarse sediments were deposited at the mouths of the streams as deltas. The finer particles remained in suspension until they reached quieter water where they were deposited on the lake bottom and accumulated to form thick beds of silt and clay. The depositional environments changed from time to time and from place to place so that clay beds alternate with thin beds of very fine sand and silt, medium sand and silt, or coarse sand and gravel.

Outwash sediments

Outwash sediments in the Wyoming Valley occur as extensive deposits of well-sorted sand and gravel that are primarily found underlying the broad flat plain in the northeastern half of the valley.

These sediments are shown on the geologic map (Plate 1) and they immediately underlie most of those deposits shown as alluvium. Their thickness ranges from a fraction of an inch to 30 feet. Good exposures of these deposits can be seen in excavation pits in the valley (Fig. 8). The sediments are generally free of silt and clay and some were sorted to the degree that the sands were removed and a clean pebble-size gravel was deposited. "These characteristics, coarseness and a high degree of sorting, are . . . features of glacial outwash. They are . . . the result of the regimen of glacial rivers (when the glaciers terminus was north of the Wyoming Valley) which commonly have diurnal floods of short duration during the summer. These floods were occasionally augmented by the runoff of heavy rains which fell over the glacier." (Peltier, p. 9, 1949.)

POST-GLACIAL GEOLOGY

Sediments left by recent floods are shown on the geologic map (Plate 1) as alluvial and alluvial fan deposits of Holocene age. The alluvial deposits occur in and along stream channels as channel fill and as a thin veneer of sediment left by flood water in low-lying areas adjacent to streams. The overbank deposits are a few inches to a few feet in thickness and occur mostly as silt and very fine sand. The channel fill deposits range from 1 to 10 feet in thickness and consist of sand and gravel that is not readily discernible from the glacial outwash deposits.

Alluvial fan deposits occur along the north side of the valley where the larger tributary streams issue from the ridges and enter the Wyoming Valley. The fans are composed of a mixture of silt, sand, and gravel.

Figure 8.
Photographs showing glacial outwash sediments, 1 mile west of Wyoming.

GROUND WATER

PRINCIPLES OF OCCURRENCE

The precipitation that falls on the area is divided into a number of parts. Part runs directly into streams, part evaporates, part is used by plants, and part percolates downward to the zone of saturation and becomes ground water. Ground water is that subsurface water in the saturated zone—the zone in which all the spaces or interstices in the rocks are filled with water under pressure equal to or greater than atmospheric pressure. In the Wyoming Valley ground water fills the interstices between the individual grains of silt, sand, and gravel in the unconsolidated deposits, and the fractures, faults, bedding planes, and some mine workings in the bedrock. In this report the discussion of ground water will be limited to the water in the unconsolidated deposits, and the water in those mines adjacent to or underlying the unconsolidated deposits.

Ground water occurs under water-table conditions and artesian conditions. Under water-table conditions ground water is not confined and the upper surface of the zone of saturation, called the water table, is free to rise and fall. Ground water is under artesian conditions when confined under pressure in a permeable rock by relatively impermeable overlying rocks. When the artesian aquifer is tapped by a well the water in the well will rise above the top of the permeable rock that contains it to a level known as the piezometric surface.

Both of these modes of occurrence are found in the water-bearing zones of the Wyoming Valley. Water-table conditions prevail in the shallow aquifer underlying most of the valley. Only in a few isolated localities could a shallow well penetrate a confining layer near the surface. Broad thick layers of clay and silt underlie most of the central part of the buried valley (Plate 2), and wells that tap water-bearing zones beneath these impermeable layers are artesian.

An aquifer is defined as part of a formation, a formation, or group of formations in the zone of saturation that will yield water to wells or springs (Meinzer, 1923, p. 30). The principal aquifer and ground-water reservoir in the Wyoming Valley is composed of the unconsolidated deposits that lie mostly in the overdeepened part of the valley below an elevation of 560 feet. The unconsolidated deposits above 560 feet elevation are generally tills, alluvial fan deposits, small isolated terrace deposits, thin channel deposits, and undifferentiated glacial debris that are not extensive enough to store or transmit large supplies of water to wells. Of the deposits below 560 feet, the coarse materials such as sand and gravel have the

greatest capacity to store and yield water because the interconnected pore spaces in these sediments are large and transmit water with relative ease.

HYDROLOGIC PROPERTIES

The quantity of water that a water-bearing material will yield to wells depends principally upon the thickness and the coefficients of permeability and storage of the material. The coefficients of permeability and storage vary with the difference in the size, shape, sorting, and packing of the grains.

The coefficient of permeability (P) of a water-bearing material is a measure of its ability for transmitting water. It is defined as the rate of flow of water, in gallons per day, through a cross-sectional area of 1-square foot under a hydraulic gradient of 1 foot per foot at a temperature of 60°F (Ferris and others, 1962, p. 72). In equation form it may be written as:

$$P = \frac{\text{volume of flow (60°F)}}{\text{(time) (cross-sectional area)}}$$

The coefficient of permeability as defined above, except that the water temperature is the prevailing field temperature, multiplied by the saturated thickness of the aquifer, in feet, is equal to the coefficient of transmissibility (T). The coefficient of transmissibility is defined as the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1-foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent. The storage coefficient is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface (Ferris and others, 1962, p. 74).

Detailed descriptions of borehole logs are useful in estimating an aquifer's hydrologic properties. However, a quantitative appraisal of the hydrologic properties usually requires comprehensive analyses of water-bearing materials by aquifer tests. The field method of measuring the transmissibility and storage coefficients consists of pumping a well steadily at a known rate of discharge and measuring the change in water level, during and after pumping, in the pumped well and in one or more observation wells nearby. These methods are described by Wenzel (1942) and by Ferris and others (1962).

Four aquifer tests were made on shallow irrigation wells in the Wyoming Valley. During each pumping test the changes in water level were meas-

ured in observation wells located at different distances from a pumped well. After pumping, measurements were continued until the water levels in the wells recovered approximately to their pre-test levels. The drawdown and recovery data obtained from the aquifer tests were analyzed by means of the Theis nonequilibrium formula and the Theis recovery formula (Ferris and others, 1962, p. 92-102), and corrected for partial penetration where applicable (Walton, 1962, p. 7). The results of these computations are given in Table 1.

Table 1. *Summary of values of transmissibility, field permeability, and storage coefficients determined by aquifer tests*

Well number	Location	Pumping rate (gpm)	Trans-missibility T (gpd per ft)	Field permeability P (gpd per sq ft)	Storage coefficient (percent)	Saturated thickness of aquifer (feet)
Lu-255	Plymouth	380	540,000	4,000	0.13	130
Lu-257	Wilkes-Barre	42	37,000	4,000	.01	9
Lu-300	Kingston	90	63,000	3,000	.03	21
Lu-305	Wyoming	100	10,600	1,800	.0002	6

The aquifer tested by pumping wells Lu-257 and Lu-300 is composed chiefly of coarse sand and gravel (outwash deposits) that lie on a relatively impermeable silt and clay formation. The aquifer tested by pumping well Lu-255 is also composed of coarse sand and gravel (end moraine?), and is 130 feet thick. The results of the aquifer tests indicate that these sand and gravel formations are highly permeable, having a permeability of 3,000 to 4,000 gpd per sq ft (gallons per day per square foot). The thickest formation would yield more water to wells screened throughout the saturated zone than the thinner formation. The aquifer tested by pumping well Lu-305 is composed mainly of medium sand and fine gravel that is confined both at the top and the bottom of thick clay formations. The results of the aquifer test show this formation to be moderately permeable, having a value of 1,800 gpd per sq ft.

Storage coefficients shown in Table 1 are representative of water table or unconfined conditions, except the value from the test on well Lu-305 which reflects artesian conditions. The coefficient of storage obtained for this test is small because the aquifer is locally confined by a clay layer, and the pumping test was not of long enough duration to dewater the confining clay bed.

The test results are useful in evaluating the lithologic character of the sand and clay mapped in the 10- to 50-foot zone (Plate 2). Results of the aquifer tests indicate that those areas mapped with sand-clay ratio between 1 and 8 have permeabilities ranging from 3,000 to 4,000 gpd

per sq ft, and the area mapped with sand-clay ratio between 0.25 and 1 have a permeability of 1,800 gpd per sq ft. Because the higher permeability values were from the outwash deposits, it is believed that those areas having outwash deposits with similar clastic ratios would yield large to moderate supplies to wells where the deposits are sufficiently saturated to be developed.

Therefore, the lithofacies map (Plate 2) may be useful in predicting areas where high-yielding wells may be developed. Those areas shown on the lithofacies maps that have the higher sand to clay ratios will have the greatest thickness of sand and gravel and will yield larger supplies of water to wells than those areas shown to have lesser ratios. Most of the buried valley material contains sand and gravel at some depth; however, in areas shown to have the least sand to clay ratios, sand and gravel beds are not thick enough to develop large-capacity wells, such as that formation tapped by well Lu-305.

To determine the depth and thickness of sand and gravel deposits at a specific location in the buried valley, logs of nearby boreholes should be consulted. Logs of boreholes, selected to give maximum coverage of the buried valley, are shown graphically in the Appendix. Their locations are shown on Plate 3.

THE WATER TABLE

The water table in the buricd valley is not level or uniform but is a sloping and undulating surface. Plate 4 shows the configuration of the water table on August 3, 1966, and May 22, 1967.

The shape of this surface is due to local differences in the capacity of the aquifer to store and transmit water, and the recharge to and discharge from the aquifer. For example, the gentle water-table gradient in the vicinity of the Wyoming Airport results from the excellent water-transmitting properties of the thick deposits of coarse sand and gravel that underlie the area. Water added to the aquifer in this area is transmitted rapidly to the Susquehanna River. To transmit an equivalent amount of water to the river, finer sediments would require a steeper gradient such as occurs in the area west of the Wyoming Airport. Other examples are the depressions in the water table over the Lance and Prospect-Henry mines. These depressions, shown on Plate 4 for the August measurement by sharp curving and reversal of the 512 and 518 contours, were caused by ground-water movement from the water-table aquifer into the mine voids below. The depression over the Lance mine was not present during the spring of 1967, when water added to the aquifer in that

area from heavy rains (Fig. 9) was equal to or greater than that seeping into the underlying mine (Plate 4, see May measurement).

Depths to the water table range from less than 10 feet below land surface near the Susquehanna River to more than 30 feet below land surface in most of the areas shown as kame terrace and alluvial fan deposits on Plate 1.

At any one place the depth to the water table fluctuates throughout the year. Water-level fluctuations are caused by changes in the rate of recharge to and discharge from the aquifer. The water level in wells rises or declines depending upon whether recharge is greater than or less than discharge, respectively. Generally, the water table is highest in the period from March through June, and it declines rapidly through the late spring and summer because of evapotranspiration. Water levels begin to rise again in October, after the growing season, to a peak in early spring.

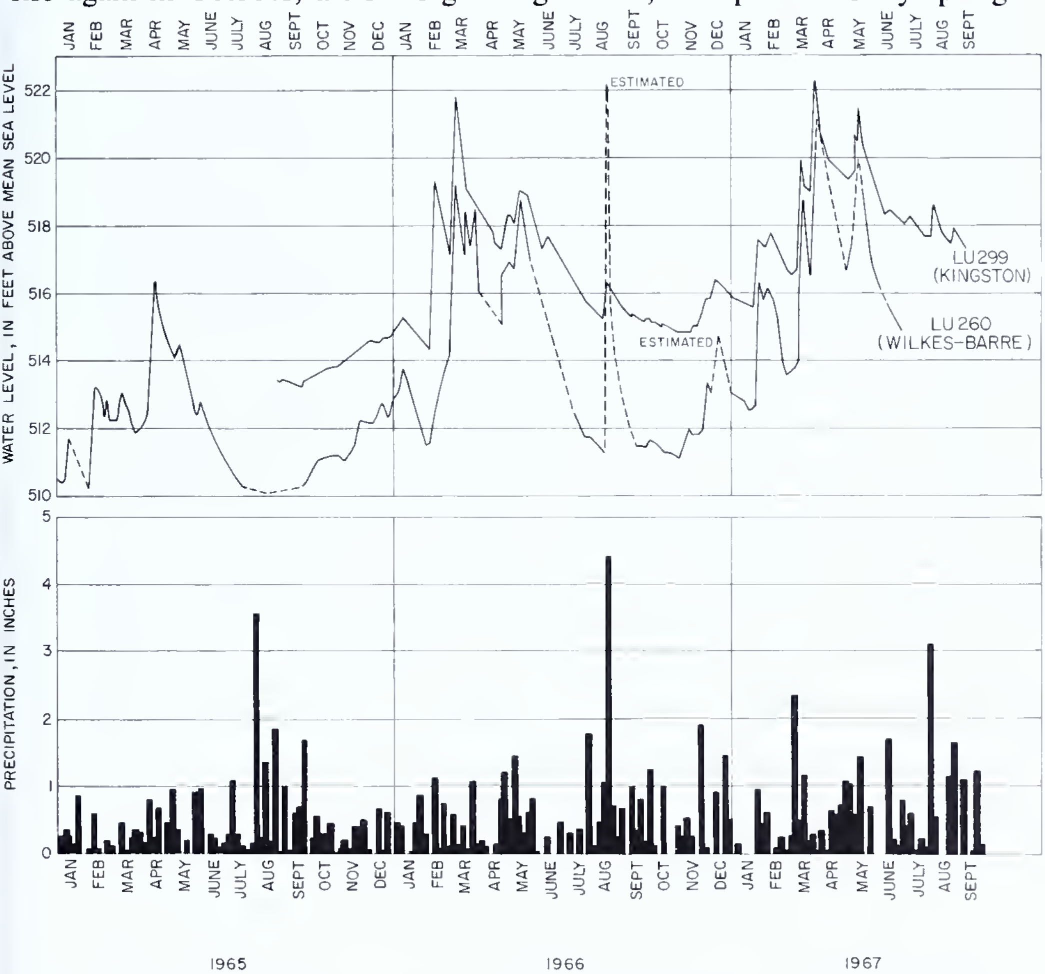

Figure 9. Hydrographs of wells located in Kingston and Wilkes-Barre and weekly precipitation totals for Wilkes-Barre.

During the period of data collection for this report (1965-67), the area experienced both drought and heavy precipitation. The resulting water-level fluctuations are shown by the hydrographs in Figure 9. The water in well Lu-260 rose nearly to the elevation of the water in well Lu-299 when the aquifer was receiving more water than it was discharging (Fig. 9), but declined farther than the water in well Lu-299 when the aquifer was discharging more water than it was receiving. The greater water-level decline in well Lu-260 was caused by the aquifer discharging water to the underlying mines.

The fluctuations in four wells equipped with automatic water-level recording instruments ranged in amplitude from 7 to 14 feet during the period of data collecting. The difference in the magnitude of the fluctuations from well to well during a particular rainfall is due mainly to the capacity of the saturated material to transmit and store water in the vicinity of each well, to local differences in the soil moisture content, and the intensity of the storm.

Fluctuations in the stage of the Susquehanna River influence the water-level fluctuations in wells near the river. The range and magnitude of the influence depends on the water-transmitting properties of the sediments, the steepness of the hydraulic gradient, and the height of the river stage. The influence diminishes with increasing distances from the river and generally does not exist at distances greater than 2,000 feet from the river.

Under water-table conditions the water level in an unpumped well stands at the height of the static water level of the surrounding aquifer. The water level inside the well drops rapidly when the well is pumped, and the water table surrounding the well approximates the shape of an inverted cone that has its apex at the center of the pumped well (Fig. 10). This cone of depression forms as a result of an adjustment in the hydrostatic pressure near the well which is defined by Darcy's equation (Ferris and others, 1962, p. 73). During pumping, the water within the aquifer moves rapidly inward and downward along and beneath the slope of the cone toward the level of the water in the well. The water level in the

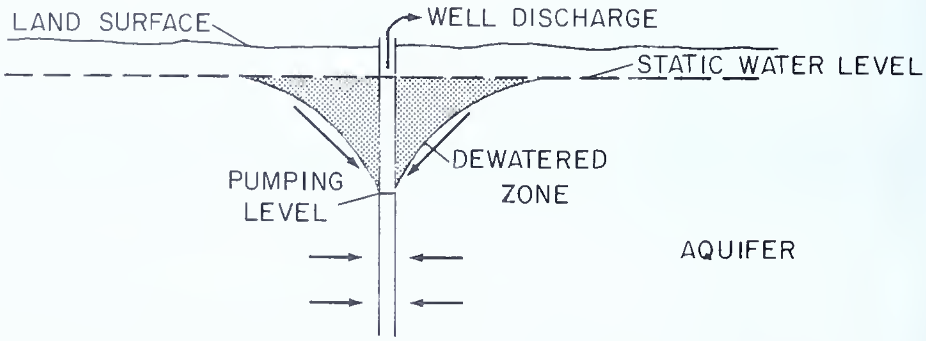

Figure 10. Illustration of the cone of depression when a well is pumped.

well drops, and the cone of depression expands outward and downward until the rate at which water moves through the aquifer toward the well is virtually equal to the rate of well discharge.

In many areas the cone of depression cannot extend indefinitely in all directions. If the discharging well is near an impermeable formation the expansion of the cone in that direction may be stopped. The cone must then develop in other directions to dewater an area that has enough recharge to balance the well discharge. Should pumpage exceed the recharge to the same area and the cone of depression cannot expand farther, then the pumpage rate will fall off and the well will go "dry".

Where pumping wells are too closely spaced the cones of depression overlap causing the cones to expand farther in a direction away from the adjacent pumped wells. The drawdowns will be excessive and the wells will yield less than they would without interference from adjoining wells.

When a cone of depression of a pumped well reaches a body of water such as that of a perennial stream (Fig. 11) the water being pumped will include water induced into the aquifer from the stream. The shape of the cone of depression is then distorted so that gradients between the stream and the well become steep in comparison to those away from the stream. In this case, flow toward the well will be greatest on the side nearest the stream. If pumping is continued for a long enough time at a constant rate, a condition of essentially steady flow will result, in which most of the pumped water will be induced from the stream.

GROUND-WATER RECHARGE

Ground-water recharge is the addition of water to the ground-water reservoir. It is accomplished mainly by infiltration of precipitation. Seep-

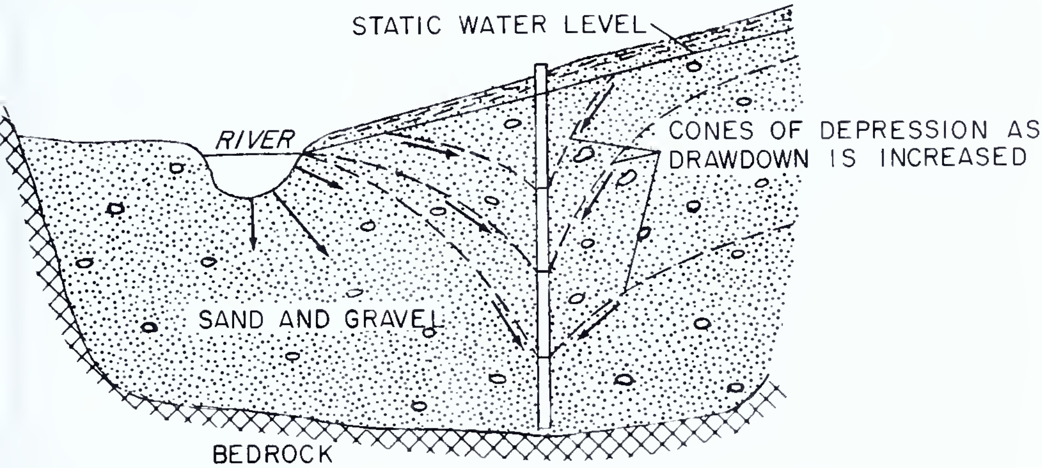

Figure 11. Illustration of the cone of depression developed when a well is pumped where recharge is induced from a perennial stream.

age from the river, streams, ponds, sewers, infiltration of irrigation, and the underflow from the adjacent fractured rock and coal mines may be important local sources of recharge to the buried valley aquifer.

Recharge from precipitation is usually most effective during late fall and early spring when losses by evapotranspiration are low. The recharge varies with the amount and distribution of precipitation and is greatest in areas underlain by more permeable surface materials, such as glacial outwash and alluvial fan deposits.

The rate of recharge to the buried valley aquifer by precipitation is computed from indirect measurement of the quantity of water moving through a part of the aquifer to the Susquehanna River. All of the area north of the river between West Pittston and Kingston was selected for the analysis.

Computation was made using a modification of Darcy's law (Ferris and others, 1962, p. 73), which in equation form is written as

$$Q_d = TIL$$

where:

Q_d is the discharge in gallons per day,
T is the coefficient of transmissibility in gallons per day per foot,
I is the average hydraulic gradient in feet per mile, and
L is the length of the shoreline of the river, in miles, across which the ground-water flow discharges into the river.

The transmissibility, determined from an average permeability of 4,000 gpd per sq. ft. and a saturated thickness of 15 feet, is 60,000 gpd per ft (gallons per day per foot). The average hydraulic gradient in this area, determined by the contour spacing on Plate 4 is 11 feet per mile. The length of shoreline of the isolated aquifer is 10 miles. Using these data the approximate rate of discharge from the aquifer in this area is 6.6 mgd (million gallons per day). The recharge to the isolated area, based on the above rate of discharge, is about 15 inches per year, which is equivalent to 39 percent of the average annual precipitation.

The average hydraulic gradient was determined from two sets of measurements, on one high and one low water table, which are not sufficient data to compute an average rate of discharge from the area. However, the recharge based upon the measured discharge, compares closely with the recharge of 35 percent of annual precipitation determined for similar deposits in the Pomperaug Basin study in Connecticut (Meinzer and Stearns, 1929). There may be some water added to the area analyzed from the mines and bedrock, however, it is not evident from the information available and is believed to be negligible. Because of the similarity in the soil and aquifers throughout the buried valley, the recharge rate should be applicable to all the buried valley sediments.

Tributary streams flowing across the unconsolidated sediments recharge the ground-water reservoir where the underlying material is permeable and the water table is lower than the stage of the stream. Streamflow data provided by W. T. Stuart, U.S. Geological Survey, show streamflow loss in five creeks that flow into the Wyoming Valley (Table 2). Some streamflow directly recharges the unconsolidated aquifer, and some is lost directly or indirectly to the underground mines through broken and caved strata in areas of coal outcrop. The indirect losses pass through the unconsolidated aquifer into the broken rock strata before entering the mines (Fig. 12).

Table 2. *Streamflow loss on five creeks that flow into the Wyoming Valley, 1956*

Name of stream	Station number shown on Plate 4	Distance downstream from outcrop of lowest mined coalbed (feet)	Flow (gpm)		
				Apr. 10	Apr. 11
Hicks Creek	145	1,000 (upstream)		2,092	2,911
	146	200 (upstream)		2,792	—
	147	[a] 300		2,821	—
	148	[a]1,000		3,082	2,463
	149	[a]2,300		3,333	—
	150	[a]3,600		3,325	1,797
				Oct. 30	
Abrahams Creek	307	1,250 (upstream)		2,411	
	308	[a]2,900		2,291	
	309	[a]5,200		1,889	
				Oct. 10	
Sandy Creek	258	750 (upstream)		65	
	259	1,050		23	
	260	[a]2,550		19	
	261	[a]3,250		1 (estimated)	
			Mar. 5	Oct. 23	Oct. 28
Brown Creek	67	1,100	896	2,365	240
	68	1,850	857	—	250
	69	2,500	608	2,028	94
	70	[a]3,850	336	2,147	0
	71	[a]5,000	221	151	—
				Oct. 25	
Coal Creek	293	350		126	
	294	1,750		88	
	295	[a]3,600		93	
	296	[a]5,400		172	

[a] Underlain by glacial deposits.

Figure 12. Section through the Harry E. mine showing mined beds and relation to the buried valley.

The data in Table 2 show that the streams generally decreased in flow in a downstream direction along the measured segments, with two significant exceptions. On April 10, 1956, Hicks Creek gained flow at every measurement station except the last one. On October 25, 1956, Coal Creek gained water on the last two stations. These gains are attributed to a high water table on the days of measurement caused by heavy rainfall two days prior to the measurement. Hicks Creek was measured again on the following day and showed substantial losses at every station downstream from the uppermost measurement.

Recharge from the Susquehanna River occurs only for relatively short periods of time and short distances from the river. Those areas severely affected by a high water table during a high river stage are the lowlands behind the river dikes and areas where subsidence has significantly lowered the land surface. Normally the water table slopes toward the river. As the river rises, the gradient near the river is reversed and water from the river recharges the ground-water reservoir. When the stage of the river declines, the gradient near the river is again reversed and this bank stored water returns to the river and the normal gradient is soon reestablished.

Infiltration of irrigation water is not a major source of recharge to the ground-water reservoir because irrigation is used only on vegetable farms during prolonged dry periods when nearly all the irrigation water is used by the plants and evaporation.

Seepage from sewers is not a major source of ground-water recharge. Leaks from sewers and deliberate injection of sewage are known to occur in the buried valley, but the sites were not located.

The amount of mine water seeping into the ground-water reservoir depends upon the hydraulic head between the mine-water pool and the ground-water reservoir, and the interconnection between the mine voids and the unconsolidated sediments. No measure of the quantity of recharge from the mines can be made because of the many complexities in the hydraulic system. The reverse condition, where the buried valley aquifer is losing water to the mines, particularly where the mine-pool altitude is greatly lowered by pumping, will be discussed in the following section.

GROUND-WATER DISCHARGE

Water in the ground-water reservoir moves from areas of high water level to areas of low water level; from areas of recharge to areas and points of discharge. Ground water is discharged naturally into streams, springs, and through evapotranspiration; and artificially by pumping from wells and mine voids below the water table.

Drainage into the Susquehanna River, and into mine voids are the most important means of ground-water discharge from the unconsolidated

aquifer in the Wyoming Valley. The rate at which ground water is discharged depends on the hydraulic properties of the aquifer and the gradient of the water table.

Ground water discharge into the river for the aquifer north of the river was computed to be 6.6 mgd. Discharge from the other aquifer segments was estimated to be 2.3 mgd; however, it is not possible to accurately determine what part of this discharge was to the river or into the pumped mines south of the river.

Evapotranspiration discharges about 10 to 15 percent of the ground water from the area. Evapotranspiration is the sum of the volumes of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from an adjacent water table in the area.

Most springs in the unconsolidated deposits in the area outside of the buried valley discharge at or near the base of the kame terrace and alluvial fan deposits. Yields from springs are small and are not considered a significant source of ground-water discharge in the Wyoming Valley.

Water discharged from wells is limited to irrigation use. Three wells are known to have been used during the recent drought for irrigating vegetable crops. Three other wells are in use for watering purposes in greenhouses (Table 3).

UTILIZATION

In Wilkes Barre ". . . Every house hoisted water from a well by a windlass and crank . . . as far back as 1830 . . ." (Smith, 1929, p. 2001) and the Wilkes-Barre pump, located in the square, supplied many homes and was used for firefighting. Wells were used for water supplies at least into the 1860's. Public water was first supplied to Wilkes-Barre by a main from a dammed pond on Laurel Run. Public water supplies continued to increase throughout the valley and dams were constructed on nearly every mountain stream. In 1896, 42 water companies were consolidated into the Spring Brook Water Supply Company that served the entire Wyoming and Lackawanna Valleys until recently when this firm was purchased by the Pennsylvania Gas and Water Co. As a result of decline in use, ground water is now used mainly for irrigation of crops during summer droughts.

DEVELOPMENT

Future development of industrial and municipal water supplies in the Wyoming Valley could be met by using ground water as a primary or supplementary source of supply. Ground water would provide a source of water without the necessity of long transmission lines and may be

Table 3. *Record of wells*

Well number: see p. 4 of text describing well-numbering system
Use: A, abandoned; Ind, industrial; Irr, irrigation; O, observation; M, mine shaft

Well number	Location number	Owner	Driller	Date completed	Altitude above sea level (feet)	Diameter of casing (inches)	Total depth (feet)	Depth to bottom of casing (feet)	Depth to water: Date measured	Depth to water: Depth below land surface (feet)	Reported yield (gpm)	Use	Field analyses of water: pH	Field analyses of water: Hardness gr/gal	Field analyses of water: Specific conductance micromhos
LUZERNE COUNTY															
Lu-255	411312N755817.1	Lesco Barney	Lesco Barney	1938	522	72	26	20	9-16-65	20	260	Irr	6.4	—	311
257	411457N755437.1	do.	do.	—	517	60	26	26	3- 2-66	16	100	Irr	—	—	750
259	411540N755403.1	do.	do.	1933	537	8	19	19	3-25-65	20	5	Irr	—	11	460
260	411433N755430.1	Martz Bus Lines	—	1926	532	6	50	—	6-20-66	18	500	A	—	—	—
299	411509N755400.1	John Price	—	1932	525	36	15	31	10-30-64	11	—	A	—	—	—
300	411509N755358.1	Garrahan Farms	F. H. Garrahan	1935	525	60	21	21	8- 4-65	11	500	Irr	—	—	600
301	411522N755403.1	Michael Kasarda	—	—	528	48	24	24	4- 6-65	12	10	Irr	—	13	523
303	411657N755143.1	Larry Omalia	Lehigh Valley Coal Co.	1951	537	5	80	80	1-27-65	20	—	A	—	—	—
304	411653N755148.1	T. G. Price	—	1935	535	10	29	29	10-30-64	21	10	Irr	—	—	—
305	411835N755037.1	CMB Corp.	Glen Alden Coal Co.	1952	546	144	25	25	8- 2-66	18	100	Ind.	—	5	213
306	411833N755114.1	U.S. Geological Survey	Ralph E. Myers	1965	546	1¼	33	33	6- 7-66	13	—	O	—	—	—
307	411905N754908.1	do.	do.	1965	543	1¼	28	28	6- 7-66	14	—	O	—	—	—
308	411547N755245.1	do.	do.	1965	532	1¼	33	33	10-12-66	13	—	O	—	—	—
309	411757N755058.1	do.	do.	1966	543	6	40	40	5-21-66	30	—	O	6.9	5	185
311	412019N754758.1	do.	do.	1966	570	1¼	38	38	5-24-66	37	—	O	7.1	26	845
312	411706N755257.1	do.	do.	1966	552	1¼	40	40	5-24-66	22	—	O	7.1	15	518
Howard Air Shaft	411938N755003.1	James Oliveri	—	—	580	—	240	130	9- 2-65	62	—	M	7.2	30	654

preferred to surface waters because of its relatively uniform temperature, quantity, and quality throughout the year. Also, it is relatively unaffected by floods and pollution from man's activities.

Development of fresh ground-water supplies from the buried valley would be limited to that water recharged by precipitation or that induced into the aquifer from the Susquehanna River. Wells pumped for municipal or industrial use could withdraw so much water that the water table would be lowered and the cone of depression expanded out to a bedrock boundary or to intercept the Susquehanna River. Should the cone of depression extend to the bedrock, induced seepage of mine water into the buried valley could occur or be increased. Should the cone of depression extend to the Susquehanna River (Fig. 11), river water would be induced into the buried valley aquifer. To pump ground water without inducing mine water, wells should be placed close to the river. Such wells would yield a mixture of ground water and river water. However, passage of induced river water through the intervening alluvium would provide a filtering action to the river water and remove suspended material, odor, taste, color, and bacteria to a degree that it should make the water suitable for many uses. Treatment of this water necessary for a particular use might be minimal.

Properly constructed wells, spaced to prevent mutual interference should be capable of sustained yields of 1,000 to 2,000 gpm. In order to develop the aquifer to its ultimate capacity and in order to measure the induced recharge, a well drilling and aquifer testing program should precede installation of production wells.

A condition may exist in some areas that would reduce the induced infiltration of river water in some areas. The bed of the river channel may be covered with fine-grained silt, by either the natural cut and fill processes of the river current or the addition of silt from coal refuse piles. The fine-grained materials of low permeability can effectively slow the passage of water into the underlying aquifer and reduce the rate of recharge to the aquifer. This condition could be corrected by appropriate procedures to clean the river bottom if necessary to induce adequate amounts of river recharge.

Pumping tests were not conducted to determine the extent that infiltration supplies are available. However, the hydrologic conditions along the Susquehanna River are favorable for inducing infiltration from the river. Such tests have been made by Rorabaugh (1956) along the Ohio River in similar deposits; these tests proved that large supplies can be developed by induced infiltration from the Ohio River. The limiting amount of water that could be induced into wells constructed along the

river would be about 432 million gpd, the lowest flow on record for the Susquehanna River at Wilkes-Barre (Busch and Shaw, 1966). However, a minimum flow occurs less than 2 percent of the time (Table 4) and, for a period of 7 consecutive days, only once during a 60-year recurrence interval (Table 5). The average discharge for the Susquehanna River at Wilkes-Barre, for 63 years of record, is 5,950,000 gpm (Busch and Shaw, 1966). With adequate flow in the river a minimum amount of induced water would be about 1 billion gpd based upon a permeability of 20 gpd per sq ft of the river bed sediments having an area approximately 800 feet across by 70,000 feet long.

Table 4. *Duration of daily flow for the period 1899-1963*

	Discharge, in gallons per minute, which was equaled or exceeded for indicated percent of time				
	2	5	10	20	30
% gpm	30,500,000	20,600,000	14,360,000	8,980,000	6,280,000
	40	50	60	70	80
% gpm	4,260,000	3,140,000	2,330,000	1,700,000	1,170,000
	90	95	98		
% gpm	720,000	580,000	450,000		

Table 5. *Magnitude and frequency of annual low flow for the period 1900-62*

Period of consecutive days	Discharge, in gallons per minute, for indicated recurrence interval, in years				
	2	5	10	30	60
7	583,000	420,000	368,000	310,000	287,000
14	628,000	449,000	390,000	328,000	305,000
30	718,000	494,000	430,000	360,000	337,000
60	898,000	583,000	494,000	410,000	380,000
120	1,436,000	808,000	583,000	494,000	449,000

WELL CONSTRUCTION

Drilled wells that end in unconsolidated material are generally cased to the bottom of the well and receive water through the open end of the casing, through slots or perforations in the casing, or through a well screen attached to the casing. The amount of intake area controls the efficiency

of the well and the most efficient method of increasing the intake area is through the use of well screens. Well screens are manufactured in many diameters and sizes of screen openings; the size of sereen opening needed being determined by the grain size of the water-bearing material. In addition, well screens are often surrounded with a gravel pack placed around the screen. This is used mainly where the water-bearing material is well sorted and fine grained. The gravel pack helps prevent the finer material from entering the well.

Three wells of the Stanton Operating Co., 3 miles north of Pittston, along the Susquehanna River, were reported by Lohman (1937, p. 138) to be 24 inches in diameter, screened and gravel packed. Each well was tested at 1,280 gpm with a drawdown of only 9 to 10 feet after 8 hours of continuous pumping.

Few wells with perforated casing are currently in use in the Wyoming Valley and only one that was screened was found during this study. Several wells were found that had been constructed by digging a large pit below the water table, with a power shovel, inserting a perforated casing 5 feet in diameter into the pit, and then back-filling around the casing with a carefully selected gravel mix of the proper size. Wells Lu-255, Lu-257, and Lu-300 were constructed in this manner and were reported to pump 800 to 1,200 gpm (Table 3) upon completion.

MINE-WATER HYDROLOGY

Water from surface streams infiltrates into underground workings mainly by leakage from streambeds through broken strata overlying the mine openings (Table 2). Precipitation and overland runoff enters the mines mainly through surface strippings and crevasses along steeply dipping beds where the surface has caved into voids below. From the points of entry, water flows through the mine workings to underground pools. These pools are bodies of water enclosed vertically between the floor and roof of the mine openings, and horizontally by barrier pillars, other unmined areas of coal and the bedrock structure. Barrier pillars are bodies of unmined coal that are left in each coalbed along the company property lines.

Mining practices with regard to barrier pillars varied greatly prior to enactment of a public law in 1891 establishing and defining the specification for barrier pillars (Ash and others, 1949, p. 9). Barrier pillars were inadvertently weakened or breached in many mines, and there is no assurance that any one barrier pillar has remained stable. During and after the filling of the mines with water, it is apparent from the elevation of the pools that there is leakage through the pillars. Stable conditions in an operating mine change during filling of a mine and become unstable.

Wetting of previously dry surfaces and several hundred feet of hydrostatic head causes minor weaknesses to become pronounced. Collapse often occurs and eventually subsidence may cause local breakage of barriers and of man-made dams in barrier openings.

The elevation of the mine-water pools on August 3, 1966, and May 22, 1967, are shown in Plate 4 for the mines that are filled with water in the Wyoming Valley. Mines interconnected by the removal of a barrier pillar in a common coalbed are shown as one mine with a common pool, although the gradient on the pool causes small differences in the individual mine pool altitudes. Water filling the mine voids froms a shoreline on the structural limits of the mines. In each pool this shoreline represents a contour on the inclined bottom or walls of the mine that moves outward or inward as the water level in the pool rises or falls.

The mine-water pools along the north side of the Wyoming Valley are stair-stepped in profile from a high in the Seneca pool to a low in the Avondale pool, with the exception of those pools affected by pumping (Figs. 13, 14 and 15). Many of the adjoining pools descend stepwise at a constant gradient, indicating free interconnection between those mines. The low water level in the Loree mine-pool on October 10, 1966, is due to leakage of water to the Lance pool in response to mine pumpage on

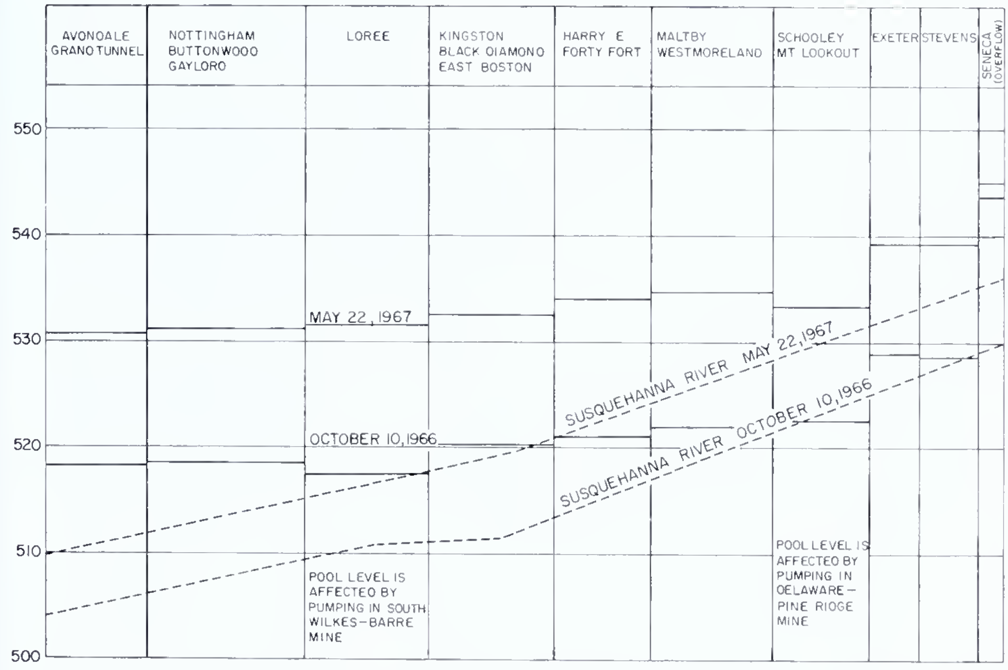

Figure 13. Diagrammatic section through the mines showing the elevation of mine-water pools and the profile of the Susquehanna River at the corresponding times.

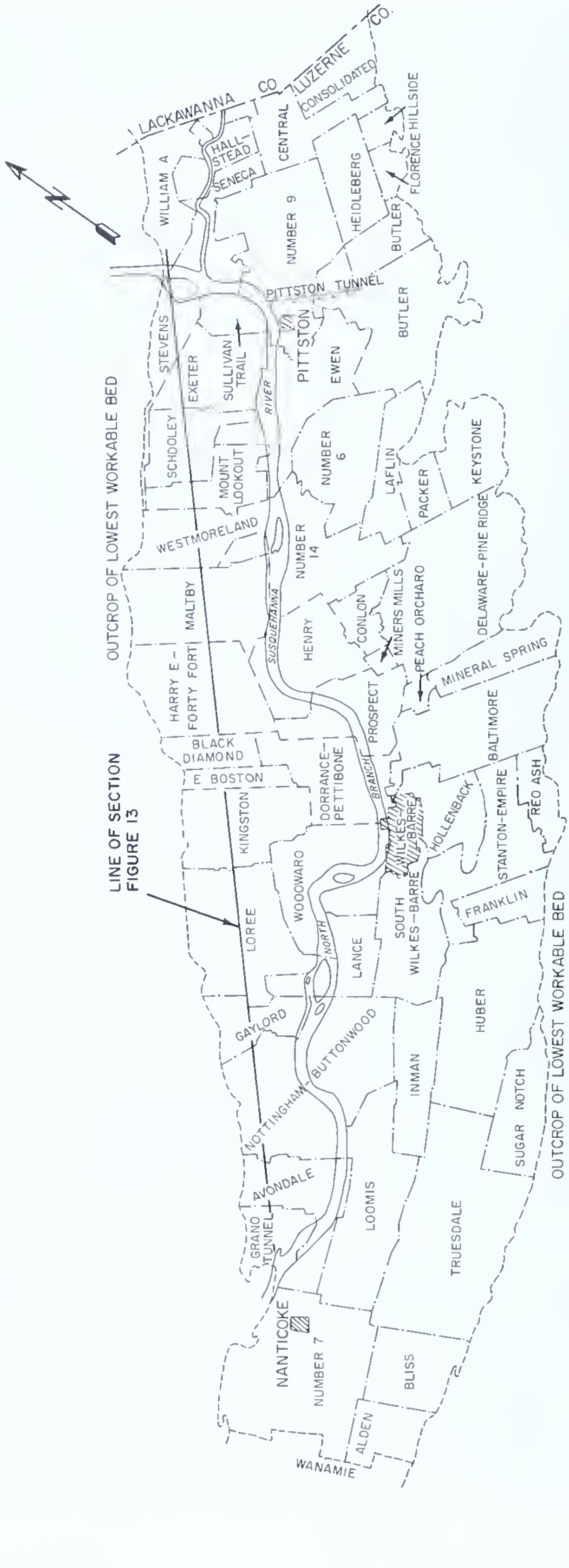

Figure 14. Map showing mining properties.

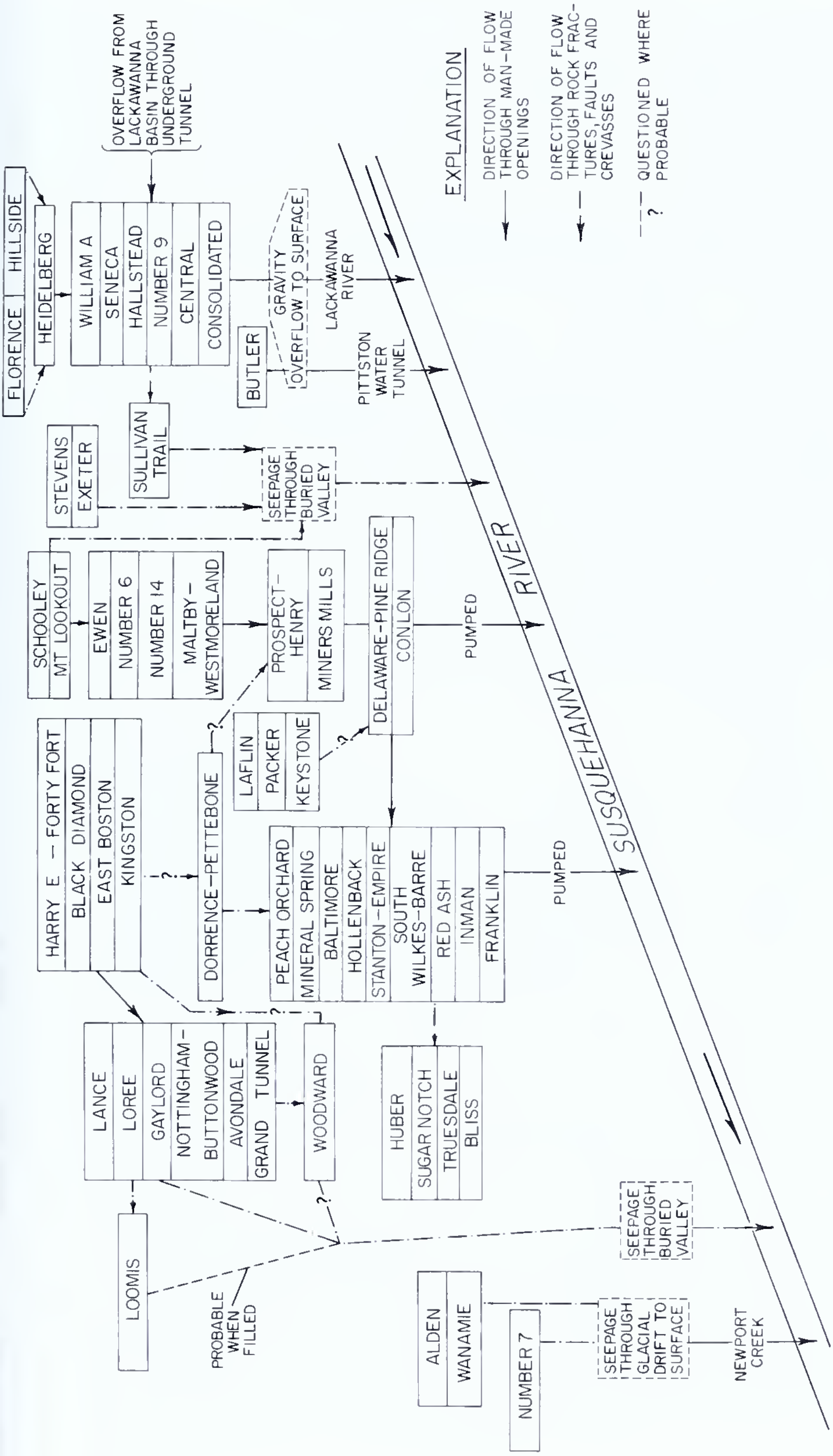

Figure 15. Schematic of water flow through the mines in the Wyoming Valley.

Table 6. *High and low mine-water levels for measured pools in the Wyoming Valley for period May 1964 through December 1967*

Location of mine opening	Location number	Elevation of measuring point	Elevation of high and low pool levels May 22, 1967	Elevation of high and low pool levels Jan. 4, 1965	Fluctuation
Avondale - Borehole No. 124A	411324N755852.1	532.36	530.52	502.7	27.8
Dorrance - Borehole No. 5222	411519N755233.1	549.33	516.28	499.64	16.6
Ewen - Borehole No. 14	411754N754956.1	564.15	534.37	514.78	19.6
Exeter - Red Ash, Main Shaft	411932N754906.1	586.61	539.15	514.69	24.5
Harry E - No. 1 Shaft	411729N755327.1	608.39	534.03	511.40	22.6
Kingston - No. 1 Shaft	411608N755427.1	570.56	532.52	505.58	18.9
Lance - Baltimore Shaft	411438N755558.1	577.16	530.75	503.15	27.6
Lance - No. 1 Shaft	411447N755542.1	548.30	531.39	509.18	22.2
Maltby - Borehole 8125	411804N755155.1	554.47	534.55	512.05	22.5
Buttonwood - No. 22 Shaft	411334N755611.1	567.43	531.16	503.38	27.8
Henry - No. 2 Shaft	411637N755132.1	566.11	522.56	505.70	16.8
Schooley Shaft	411919N754926.1	564.85	533.22	505.43	27.8
Seneca - Phoenix Shaft	412054N754627.1	572.69	552.45	543.43	9.0
Stevens Shaft	412023N754847.1	567.30	539.25	514.05	25.2
Sullivan Trail - Clear Spring Shaft	412011N754801.1	579.75	538.29	521.06	17.2
Woodward - No. 3 Shaft	411505N755339.1	552.58	527.62	503.46	23.2
				Average	22.00 ft.

the south side of the valley. High and low pool levels are shown in Table 6 for each measuring site for a period of record starting May 1964, when, all the pools on the north side of the valley were filled. The Dorrance pool level is also greatly affected by pumping on the south side of the valley.

The fluctuations of the mine-water pool in the Maltby-Westmoreland mines are shown in Figure 16. The mine-water pools attained their highest levels during May 1967, due to heavy rainfall in March and April (Plate 4).

Generally, all the mines in the Wyoming basin are interconnected to some degree; however, the pattern of flow between the water-filled mines is extremely complex. Known openings, discussed by Ash (1954), are useful for defining the flow path through most mines, but the effectiveness of the barrier pillars in restricting the movement of the water obviously cannot be defined. The movement of water through individual mine pools is shown on Figure 15, generally, in the sequence of flow, from the highest pools north of Pittston, to the lowest pools near Nanticoke. Water movement in midvalley was controlled until late 1967 by pumping from the Delaware-Pine Ridge, South Wilkes-Barre and Loomis mine pools to prevent inundation of the active mines: Huber, Sugar Notch, and Truesdale.

In October 1967, the underground mining operations in Huber, Sugar Notch, and Truesdale mines ceased. Consequently, the pumping from the Delaware-Pine Ridge, South Wilkes-Barre, and Loomis mine pools ceased and the mines began filling with water. Should the mines be allowed to fill above the elevation 540 feet, flooding of basements would likely occur in buildings throughout the center lowland in the valley. To prevent flooding and subsidence the Pennsylvania Department of Environmental Resources, Division of Mines and Mineral Industries has proposed pumping the South Wilkes-Barre and Delaware-Pine Ridge pools and maintaining the pool level at about elevation 475 feet. When the Huber, Sugar Notch, Truesdale, and Bliss mines are filled above the pool level maintained in the South Wilkes-Barre mine their flow will then be to the South Wilkes-Barre pool.

Because of the high water table that caused flooding of basements during the spring of 1967 (Plate 4) the Division of Mines and Mineral Industries undertook the construction, at river level, of a water tunnel to a mine shaft near the Buttonwood No. 22 Shaft (Plate 4). The tunnel was constructed to drain off the Nottingham-Buttonwood pool at altitude 519 feet into Solomans Creek and in turn drain those pools directly interconnected with the Nottingham-Buttonwood mine.

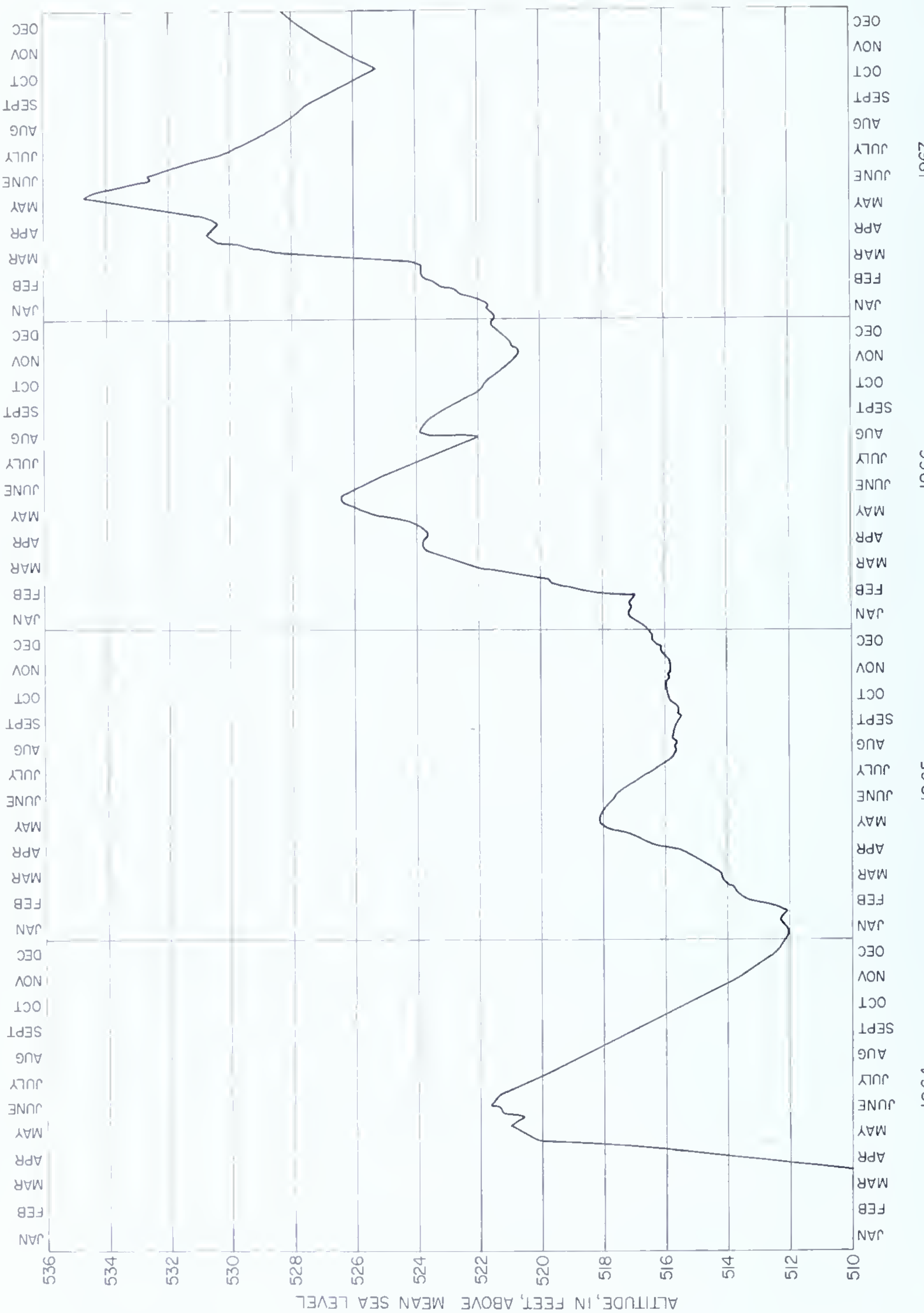

Figure 16. Hydrograph of the mine pool in the Maltby-Westmoreland mines.

MINE-WATER DISCHARGE INTO THE BURIED VALLEY

The quantity of mine-water discharged through the buried valley deposits to the river depends upon the transmissibility of the bedrock strata and the buried valley deposits, and the hydraulic head differential between the mine water and the water in the buried valley. The head on the pools formed along the north side of the valley (Plate 4) is several feet higher than that of the land surface of the valley plain. However, during average water-level conditions the hydraulic head on most pools is not great enough for large amounts of mine water to seep upward into the buried valley. Mine water seepage is probably greatest in the Plymouth-Nanticoke area where the buried valley material is very coarse, has the greatest permeability, and the head differential between the ground-water table and the mine-water pools is greatest (Plate 4).

Areas of known and probable mine-water seepage and overflow are shown on Plate 3. The known seepages and overflows are visible on the surface. Areas of probable mine-water seepages are suspected on the basis of: (1) relationship of adjacent mine-water pools, (2) severe local surface disturbance caused by mining, and (3) large amounts of seepage from the buried valley sediments to a mine, recorded during active mining (2 and 3 are known from personal communication with mining engineers). These areas should be investigated before developing a municipal or industrial supply well or well field in the buried valley sediments nearby, because additional induced mine-water recharge could add to the cost of treating the water supply.

A considerable amount of outflow may occur through boreholes that were drilled into the mines to alleviate surface drainage problems and to dispose of sewage. Prior to the filling of the mines many boreholes were drilled through the bottom of storm sewers into the buried valley where gradients on the sewers were reversed by subsidence and they would no longer drain. If these boreholes penetrated a mine void, mine water may now flow upward into the buried valley deposits. Boreholes drilled to dispose of sewage are known of only by hearsay as such holes are forbidden by state law.

Unless measures are taken to control water levels of mine pools, leakage from the mines into the buried valley may create a higher and steeper water table, and consequently cause wet basements and water-logged low-lands. Low areas will be affected first by the higher water table. Much of the area has experienced subsidence because of extensive mining, and those areas that have subsided over 8 feet will be affected by a high water table. Some of the natural river plain that was filled with dredged

channel sand and gravel and breaker refuse may also be susceptible to water-table flooding.

During the spring of 1967, heavy precipitation caused a high water table (Plate 4) which flooded some basements in Kingston. Periodic flooding of basements, due to a high water table, is expected; however, where individual basements receive seepage over several months it is believed that the source maybe leakage from a nearby sewer or borehole. The analyses of this water cannot be used as conclusive evidence that it comes from the mines. Water of similar quality may be derived from areas where breaker refuse was used as landfill, which is the case in much of the troubled area.

QUALITY OF WATER

All ground water contains dissolved mineral matter. Knowledge of the dissolved mineral constituents is important because the amount and character of the material present in the water determines its usefulness. For some purposes the quality of the ground water may necessitate treatment. The chemical composition and the amount of the dissolved solids are influenced mostly by the composition of the soil and rock through which the water has passed and the length of time the water has been in contact with the soil and rock.

Seepage of mine water into the buried valley aquifer will affect the quality of the water in the aquifer. Coal and associated strata contain finely disseminated pyrite that is dissolved and the byproducts removed by circulating mine water. The vast amounts of pyrite exposed during mining contribute large quantities of sulfate and iron to the mine water that are undesirable in excessive amounts.

Samples were taken from 10 wells for chemical analyses to determine the character of the water in the shallow aquifer. The samples were analyzed according to methods described in Rainwater and Thatcher (1960). Results of the chemical analyses are given in Table 7.

The water in the buried valley deposits is of the calcium-bicarbonate-sulfate type, hard, and high in dissolved solids. The chemical character of water from the first seven wells listed in Table 7 (those numbered between 255 and 305) is generally the same. Water from the wells that tap the finer-grained aquifers, has a higher dissolved-solids content. The sample from well Lu-305 was low in dissolved-solids—probably because the main source of recharge to this confined aquifer is from the north, primarily through seepage from mountain streams that contain only small amounts of dissolved mineral matter. Contamination by downward percolation

Table 7. *Chemical analyses of ground water in the Pleistocene deposits in the Wyoming Valley, Luzerne County, Pa.*
(Results in milligrams per liter)

Well number: see p. 4 of text describing well-numbering system.

Well number	Location number	Date of collection	Depth of well	Temperature (°C)	Silica (SiO_2)	Total iron (Fe)	Total manganese (Mn)	Calcium (Ca)	Magnesium (Mn)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids (residue at 180° C)	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific conductance (micromhos 25°C)	pH	Color	ABS
Lu-255	411312N755817.1	9-16-65	26	10.6	14	—	—	38	9.7	4.1	1.9	34	86	10	0.1	24	—	222	136	107	311	6.7	3	—
257	411457N755437.1	7- 7-66	26	11.1	15	.25	0.00	114	16	12	2.0	217	120	24	0.0	34	0.1	465	351	173	673	6.9	2	0
259	411540N755403.1	3-25-65	19	—	10	.21	0.00	50	1.3	16	5.0	81	101	23	0.0	28	0.0	301	179	112	460	6.4	4	—
300	411509N755358.1	8- 4-65	21	12.2	19	.07	—	91	16	14	2.0	141	42	24	0.0	31	—	441	295	178	618	6.9	5	—
301	411522N755403.1	4- 6-65	24	—	17	[a] 1.0	0.00	66	15	14	2.7	72	164	18	0.0	10	0.00	368	226	167	523	6.2	5	—
304	411653N755148.1	3-24-65	29	—	7.0	.19	0.00	37	12	9	2.4	46	102	19	0.0	1.6	0.00	232	142	105	361	6.3	5	—
305	411835N755037.1	8- 2-66	25	10.0	9.1	[a] .87	1.2	25	5.5	6	1.8	63	36	8.9	0.0	0.2	—	135	85	34	213	6.3	8	—
309[c]	411757N755058.1	5-21-66	40	—	5.6	—	—	22	5.6	4.9	1.7	46	31	9.5	0.1	5.1	—	115	78	41	185	6.9	60	—
311	412019N754758.1	5-23-66	38	15.6	15	[a]25	17.2	106	42	11	4.8	325	173	18	0.1	0.8	—	[a]545	437	171	845	7.1	5	—
312	411706N755257.1	5-24-66	40	13.3	13	[a]26	22	90	7.6	10	2.2	186	107	9.7	0.0	0.3	—	347	256	104	518	7.1	5	—
Howard Air Shaft	411938N755003.1	9- 2-65	—	12.8	13	—	—	104	22	5.0	5.4	207	185	4.0	0.1	1.1	—	472	350	181	654	7.4	3	—

[a] Value exceeds maximum concentrations recommended by the U.S. Public Health Service (1962)

[c] Sewerage discharged into ground nearby

of water that contains higher concentrations of dissolved solids is retarded by the confining clay bed in the vicinity of the well.

There are several sources of the high sulfate content in the ground water:

(1) The main source is from the leaching by percolating waters of pyrite (iron disulfide) from the waste rock removed from coal mines and strip mines. When coal and coal-bearing strata are removed from the ground and exposed to the atmosphere in rock dumps, refuse banks, or landfill, the sulphuric materials are readily leached out of the broken rock by percolating waters and eventually reach the ground-water reservoir in the buried valley. There are many mine breaker refuse banks and dumps in the area and the refuse is used for fill material. These many sources are enough to increase the sulfate content in the water in the buried valley aquifer. A large refuse bank upgradient from well Lu-312 (Plate 4) and refuse material used as fill in the swamp area near well Lu-311 are the source of high iron, manganese, and sulfate content in the water samples from these wells. Evidence of leached minerals deposited in the sediments underlying waste rock piles is seen north of Swoyersville in terrace deposits. It is easily recognized by the orange coating on the grains of the deposit.

(2) The atmosphere in the Wyoming Valley often contains substantial amounts of sulfur dioxide and sulfur trioxide produced by burning culm banks. Air movements are restricted because of the topography and gases from the burning culm banks are concentrated and confined to the valley bottom, especially when weather conditions are favorable for precipitation. The absorption of this sulfur dioxide from the atmosphere by precipitation will add to the sulfate content of the ground water. Carroll (1962) states that up to 8 milligrams per liter (mg/l) of sulfate may be contained in rainwater.

(3) At the present time (1968) a minor source would be from seepage of mine water into the buried valley. An example of the chemical quality of mine water seeping into the buried valley may be similar to that sampled from the Howard airshaft (Plate 4) in the Schooley Colliery. The shaft penetrated the uppermost coal seam at a depth of about 130 feet. The quantity of dissolved constituents (Table 7) in a sample taken opposite the mined coal seam are characteristic of mine water; however, the quantity of dissolved constituents are not much greater than those in most of the samples taken from wells.

The samples for wells Lu-255, 257, 259, 300, and 301 all have moderately high nitrate contents that were probably derived from agricultural fertilizers applied to croplands in the vicinity of the wells. The nitrate

content of the sample from well Lu-309 results from pollution by a nearby sewage discharge.

The Suquehanna River quality deteriorates considerably in its passage through the Wyoming Valley, due to the addition of mine-water overflow and pumped mine water. The quality of the river varies greatly with its flow and the discharge of mine water into the river. For a comparison of the general characteristics of the river water, the following analyses of samples taken near Nanticoke were obtained from the Pennsylvania Department of Health.

Date	Stream flow (cfs)	pH	Alkalinity (mg/1)	SO_4 (mg/1)	Fe (mg/1)	Mn (mg/1)	Hardness (mg/1)	Total solids (mg/1)
1-11-66	11,260	7.2	33	66	3.4	0.4	90	160
4- 5-66	12,220	7.2	48	43	1.2	.3	80	142
6-29-66	3,480	6.8	61	86	1.2	.9	152	280

High sulfate, iron and manganese deter the water's usefulness; however, only during periods of extremely low flow does the concentration of iron and manganese greatly exceed that recommended by the U. S. Public Health Service (1962) for human consumption. Treatment plants to be installed in the Wyoming Valley will significantly reduce the concentration of these constituents imposed upon the Susquehanna River on its passage through the valley.

Should the buried valley aquifer be pumped heavily for large supplies of ground water with the intent of inducing river water, the quality of the river during periods of extremely low flow will determine the extent and type of treatment necessary for a particular use. The filtering of the river water in passage through the aquifer and the mixing of ground water with the infiltrated river water may provide water that needs little or no treatment. To determine the quality of such water, a long-term pumping test on a well located near the river with periodic sampling and temperature measurements of the pump discharge, should be made. A change in the quality and temperature of the discharge would indicate a connection between the river and the aquifer and ultimately the character of the water.

CONCLUSIONS

The unconsolidated sediments filling the buried valley beneath the Susquehanna River flood plain form the best source in the Wyoming Valley for future development of large supplies of ground water. Borehole data

show that 30 to 50 feet of coarse sand and gravel underlie the Susquehanna River flood plain and adjacent low terraces. This glacial outwash is ideal for the development of large supply wells that utilize well-screens.

The transmissibility of the buried valley sediments ranged from 10,000 to 540,000 gpd per ft at four test locations. The average transmissibility of the glacial outwash aquifer is 50,000 gpd per ft.

The average natural discharge from the glacial sediments to the Susquehanna River was computed at 9 mgd. This indicates the maximum amount of fresh water available for water supply wells without inducing additional recharge from the river. However, a minimum of 700 million gpd of additional water may be induced from the Susquehanna River with a probability of inducing over a billion gpd. Sustained yields of 1,000 gpm and more are available from properly constructed and spaced wells in the permeable materials near the river. Water from the glacial outwash deposits offers several advantages over that from surface supplies, because of its year around relatively constant temperature, quantity, and quality.

Recent filling of anthracite mines in the bedrock beneath the buried valley sediments has created a complicated hydrologic system where mine pools recharge the buried valley sediments and locally the buried valley sediments recharge the mine pools. Local high ground-water levels have caused wetting of basements and other subsurface structures constructed within the zone of water-table fluctuations. Seepage of mine water into the buried valley and ultimately to the Susquehanna River occurs in areas where mining has severely disrupted the intervening bedrock. These areas may have to be avoided and will require extensive investigation before development for ground-water supplies in the Wyoming Valley.

Chemical analyses show that the ground water in the area is generally suitable for domestic and industrial use. The water is moderately hard, and locally high in dissolved solids. Ground water containing high dissolved solids is a result of the leaching of sulfides from mine waste on the surface. In two wells sampled the concentration of iron exceed that concentration recommended by the U.S. Public Health Service (1962) for human consumption.

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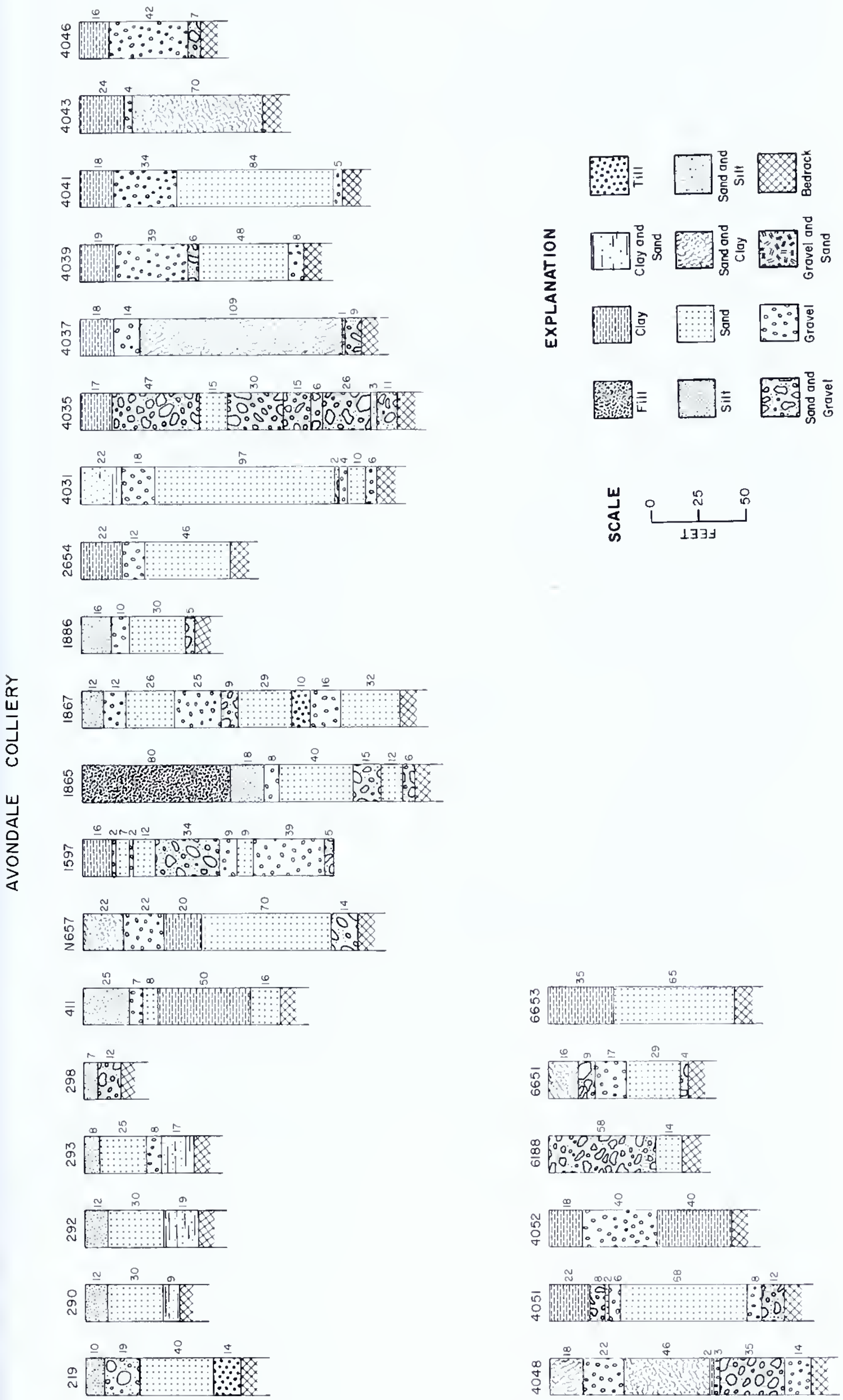
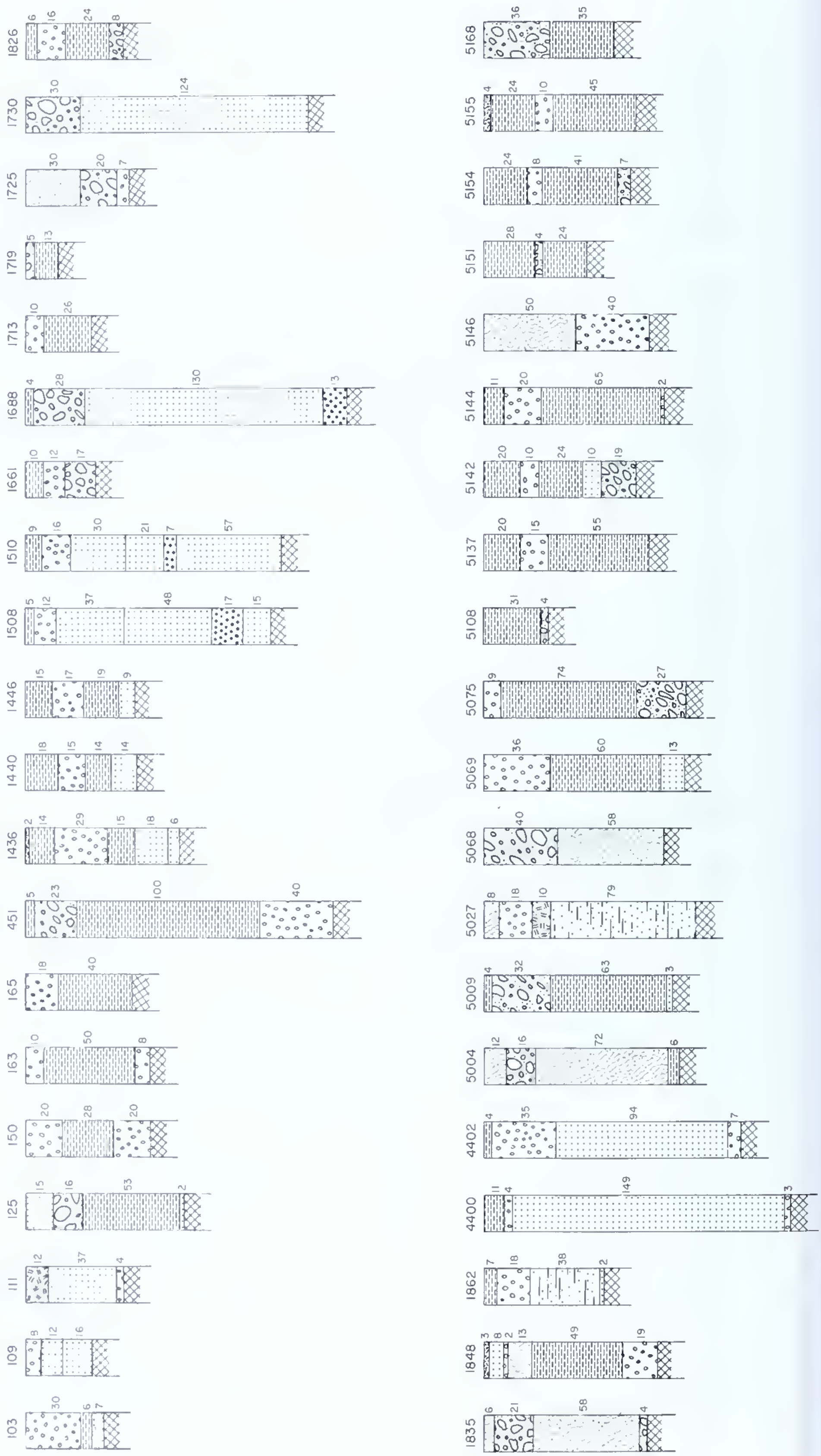
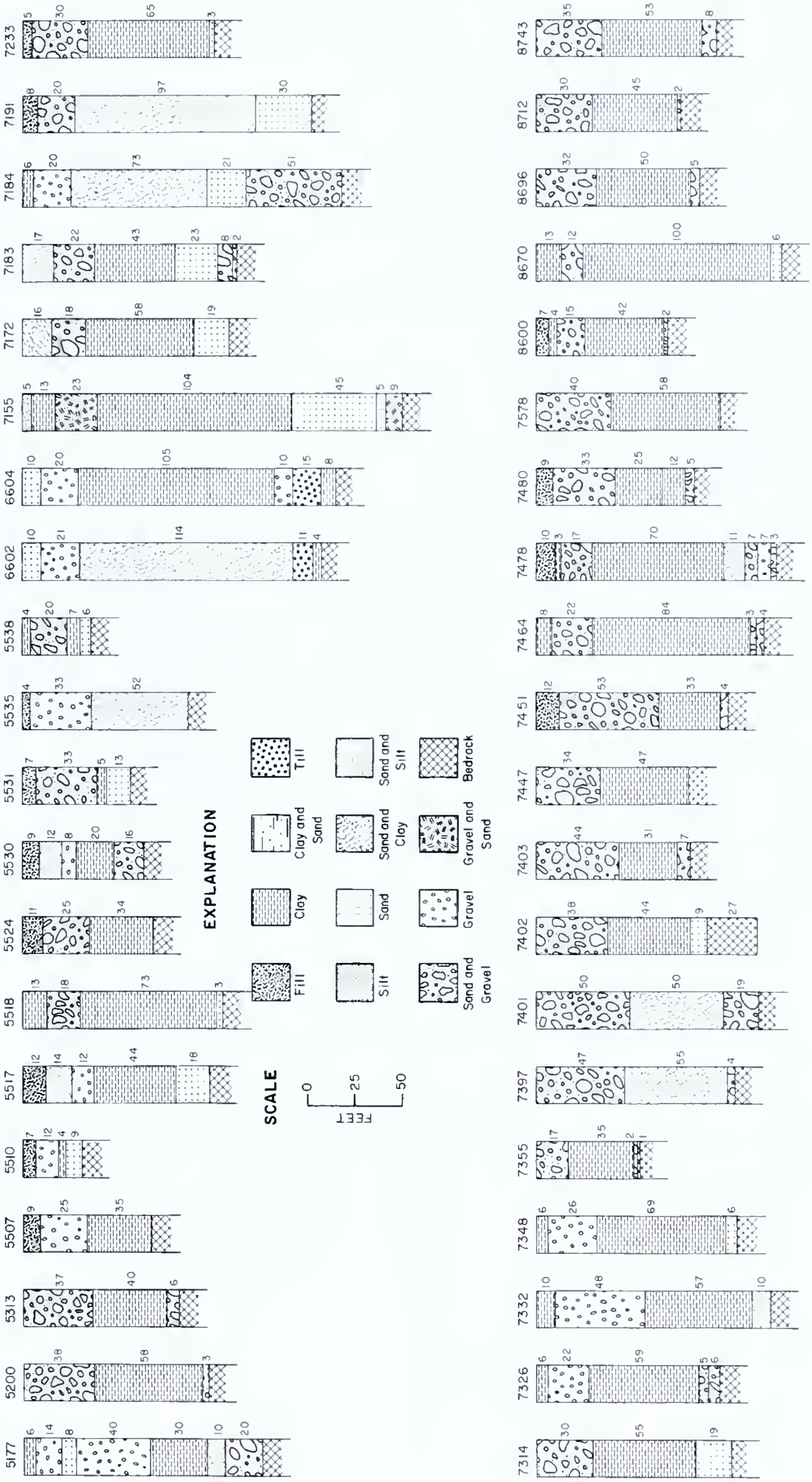
APPENDIX

GRAPHIC LOGS

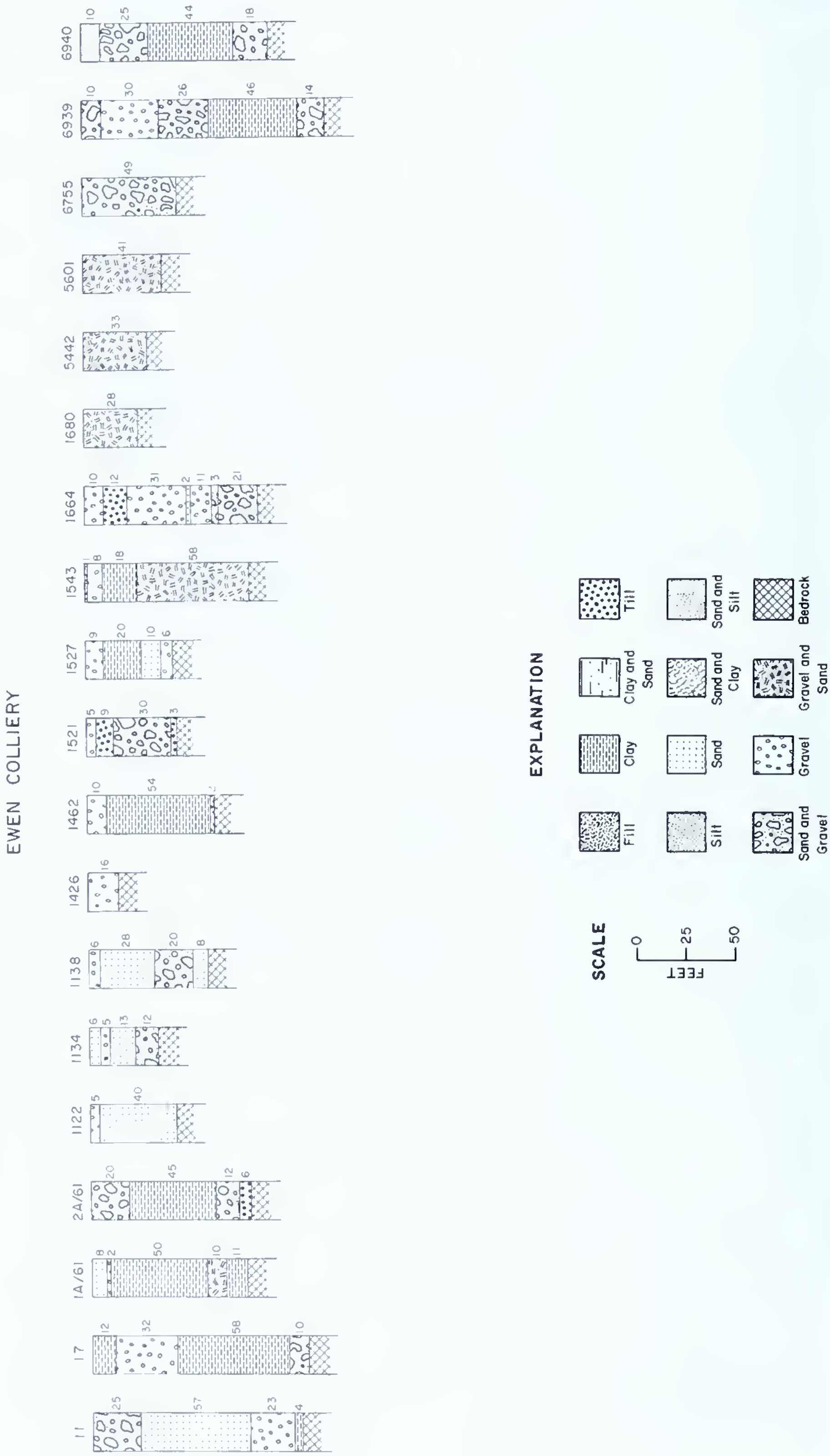

AVONDALE COLLIERY
4046
4043
4041
4039
4037
4035
4031
2654
1886
1867
1865
1597
N657
411
298
293
292
290
219
6653
6651
6188
4052
4051
4048
EXPLANATION
Till
Sand and Silt
Bedrock
Clay and Sand
Sand and Clay
Gravel and Sand
Clay
Sand
Gravel
Fill
Silt
Sand and Gravel
SCALE
0 25 50
FEET

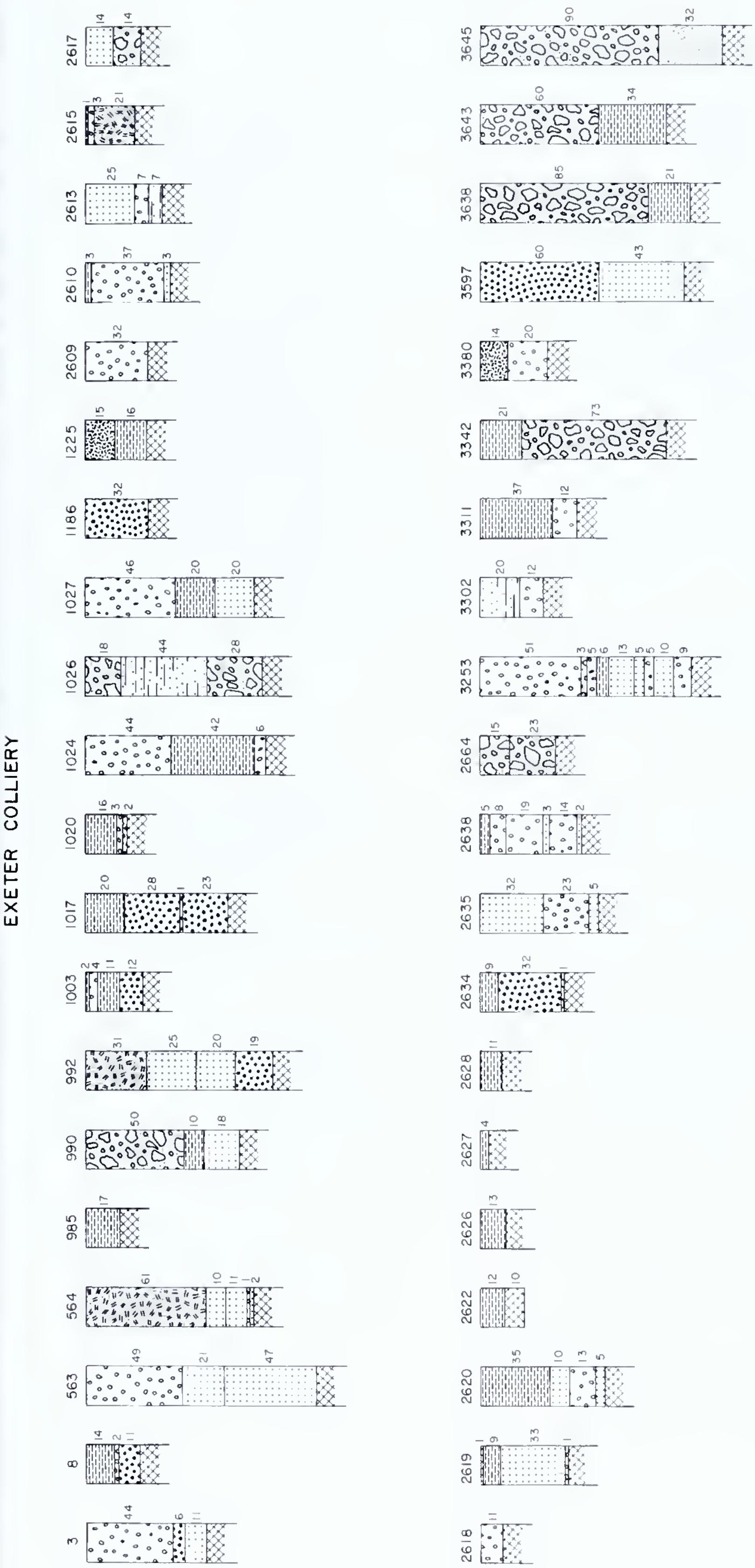


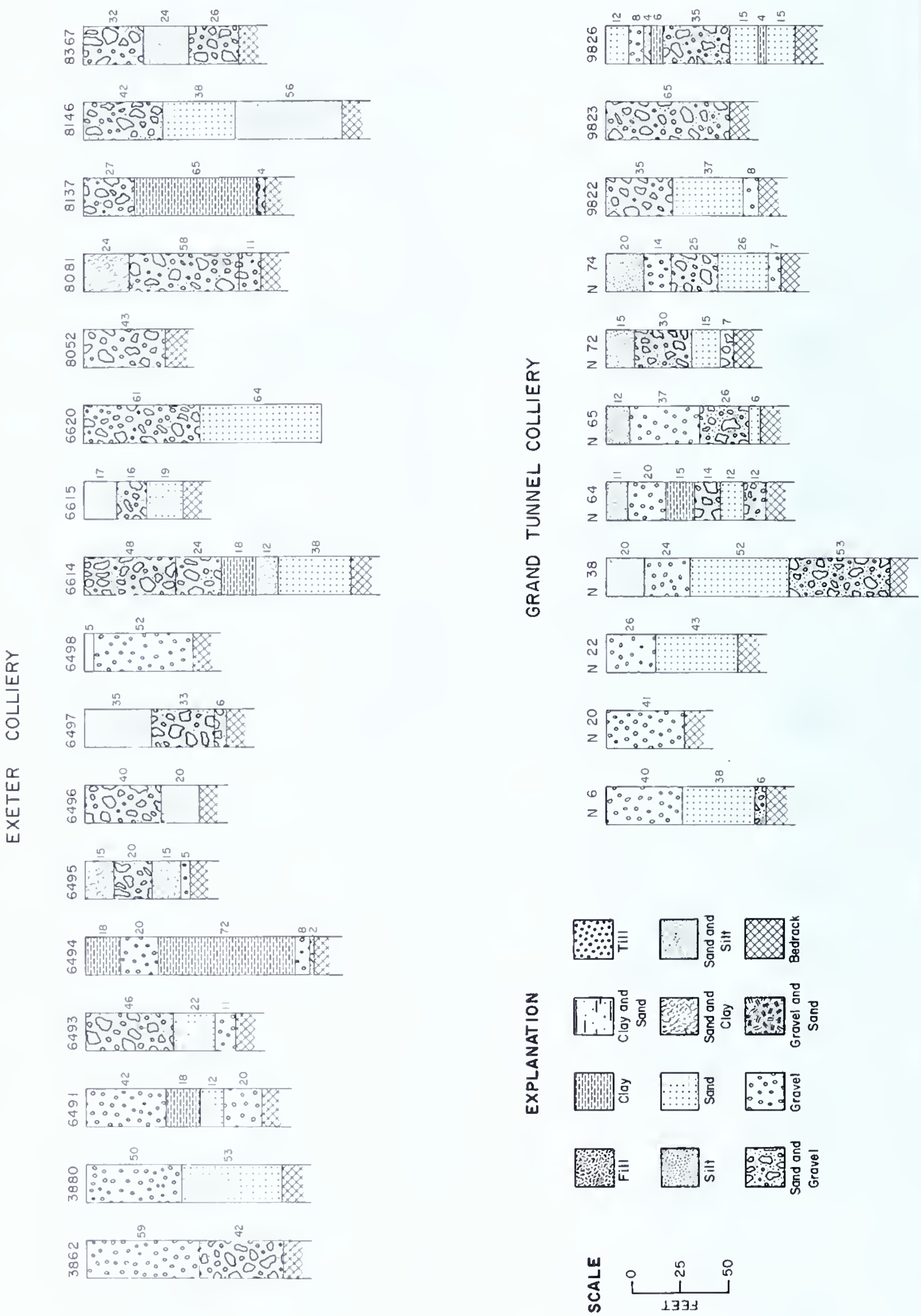
DORRANCE – PETTIBONE COLLIERIES

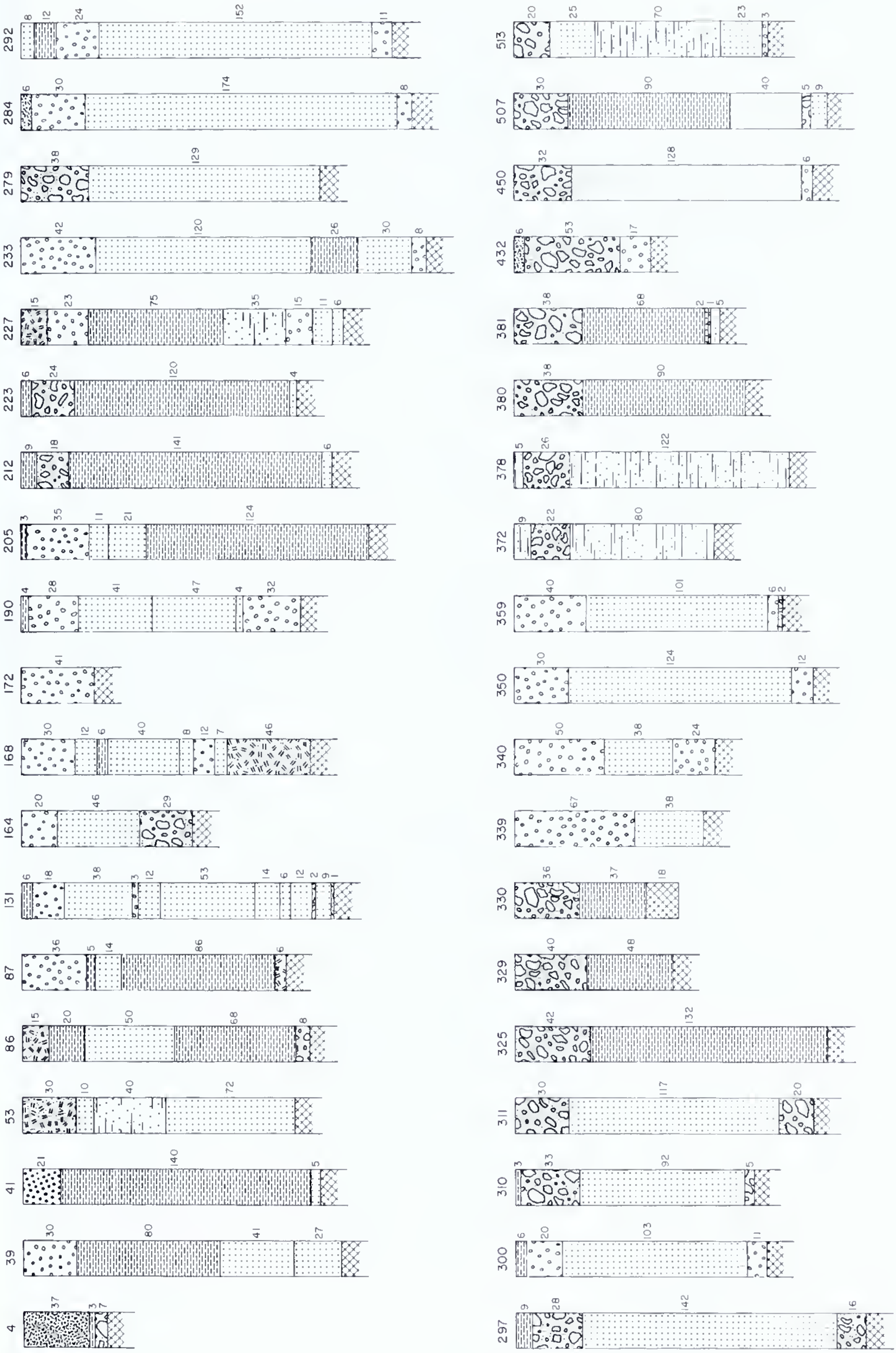


DORRANCE-PETTIBONE COLLIERIES

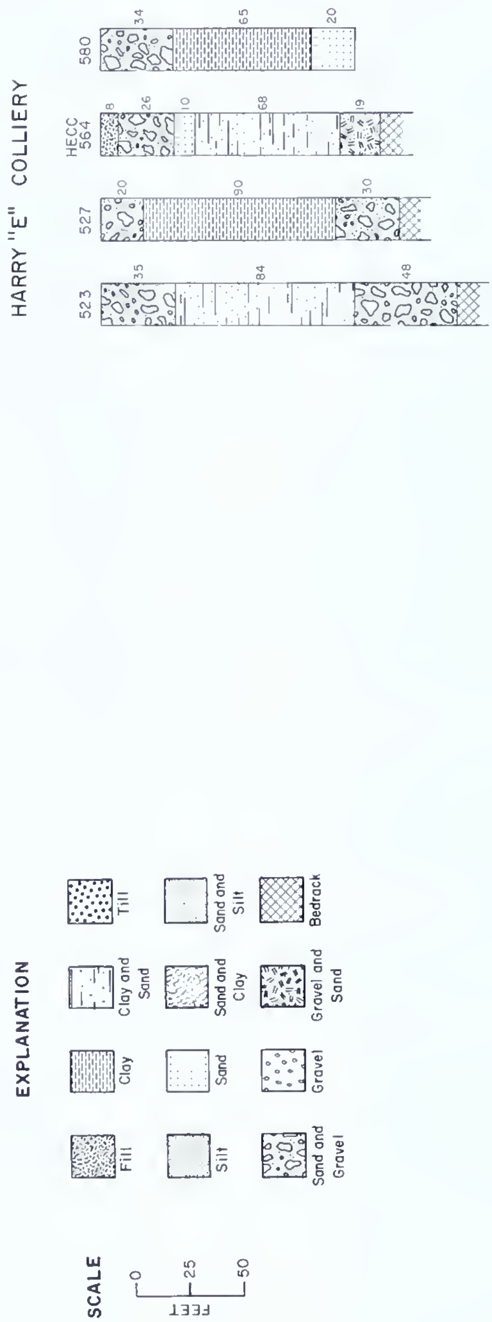

EWEN COLLIERY
6940
6939
6755
5601
5442
1680
1664
1543
1527
1521
1462
1426
1138
1134
1122
2A/61
1A/61
17
11
EXPLANATION
Fill
Clay
Clay and Sand
Till
Silt
Sand
Sand and Clay
Sand and Silt
Sand and Gravel
Gravel
Gravel and Sand
Bedrock
SCALE
0
25
50
FEET

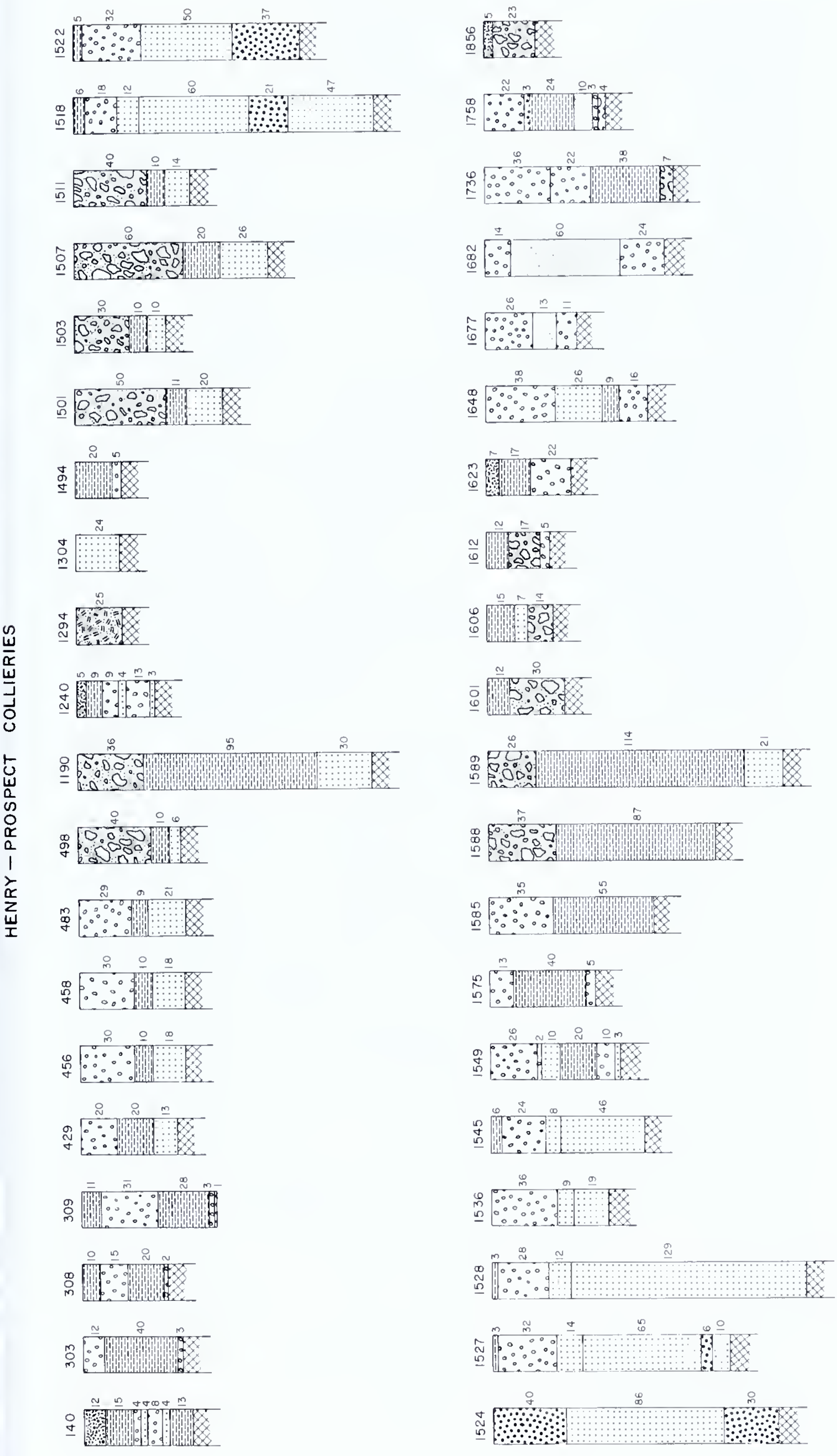

EXETER COLLIERY
2617
2615
2613
2610
2609
1225
1186
1027
1026
1024
1020
1017
1003
992
990
985
564
563
8
3
3645
3643
3638
3597
3380
3342
3311
3302
3253
2664
2638
2635
2634
2628
2627
2626
2622
2620
2619
2618


EXETER COLLIERY
8367
8146
8137
8081
8052
6620
6615
6614
6498
6497
6496
6495
6494
6493
6491
3880
3862
GRAND TUNNEL COLLIERY
9826
9823
9822
N 74
N 72
N 65
N 64
N 38
N 22
N 20
N 6
EXPLANATION
Fill
Clay
Clay and Sand
Till
Silt
Sand
Sand and Clay
Sand and Silt
Sand and Gravel
Gravel
Gravel and Sand
Bedrock
SCALE
0
25
50
FEET



HARRY "E" COLLIERY


HARRY "E" COLLIERY
580
34
65
20
HECC 564
8
26
10
68
19
527
20
90
30
523
35
84
48
EXPLANATION
Fill
Silt
Sand and Gravel
Clay
Sand
Gravel
Clay and Sand
Sand and Clay
Gravel and Sand
Till
Sand and Silt
Bedrock
SCALE
0
25
50
FEET


HENRY — PROSPECT COLLIERIES
1522
1518
1511
1507
1503
1501
1494
1304
1294
1240
1190
498
483
458
456
429
309
308
303
140
1856
1758
1736
1682
1677
1648
1623
1612
1606
1601
1589
1588
1585
1575
1549
1545
1536
1528
1527
1524


HENRY – PROSPECT COLLIERIES
5736
5713
5703
5688
5673
5642
5628
5619
5611
5564
5563
5553
5298
5265
5205
5089
5082
5055
5048
1867
7775
7757
7751
7711
7649
5978
5952
5945
5935
5918
5907
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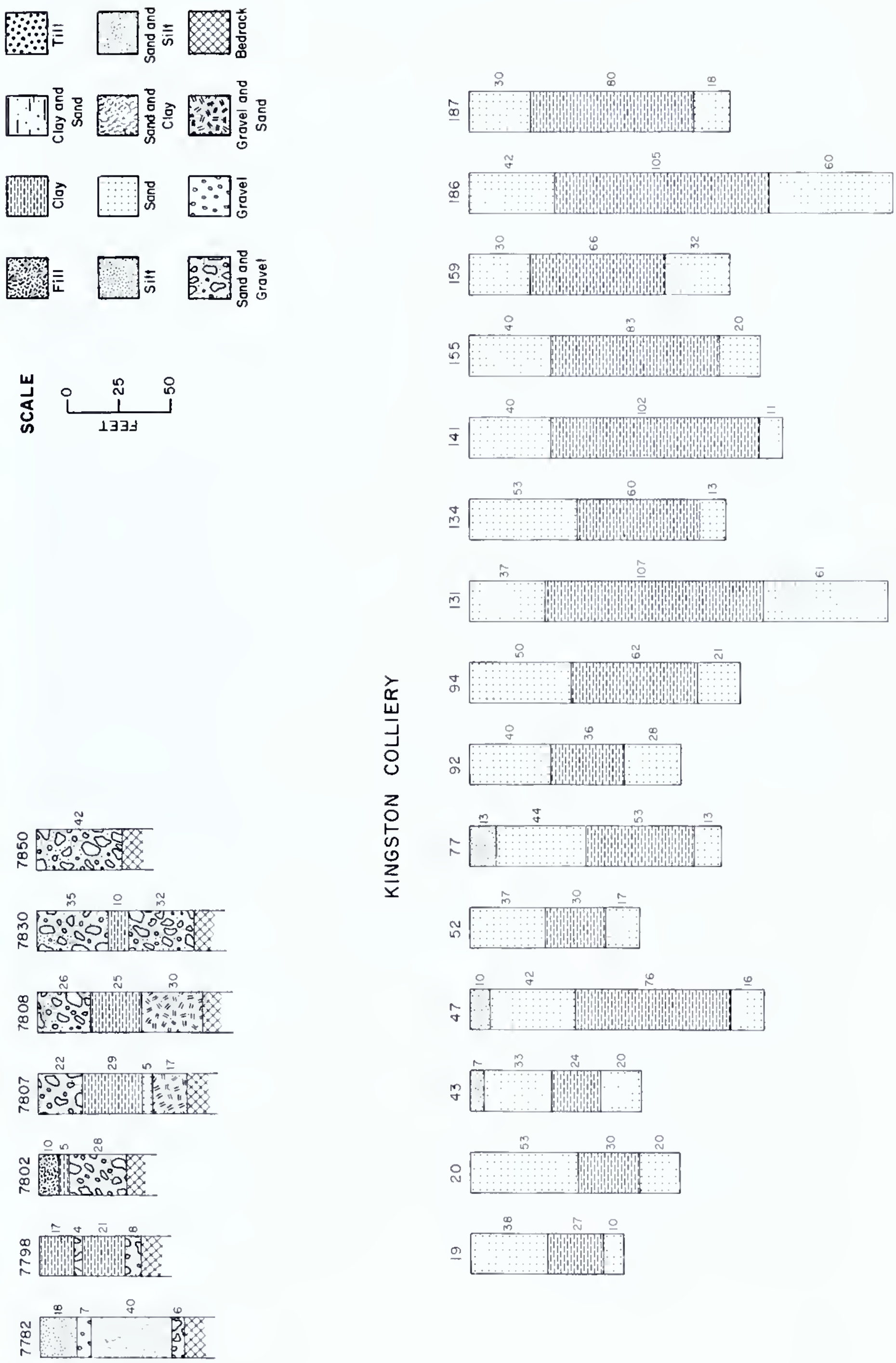
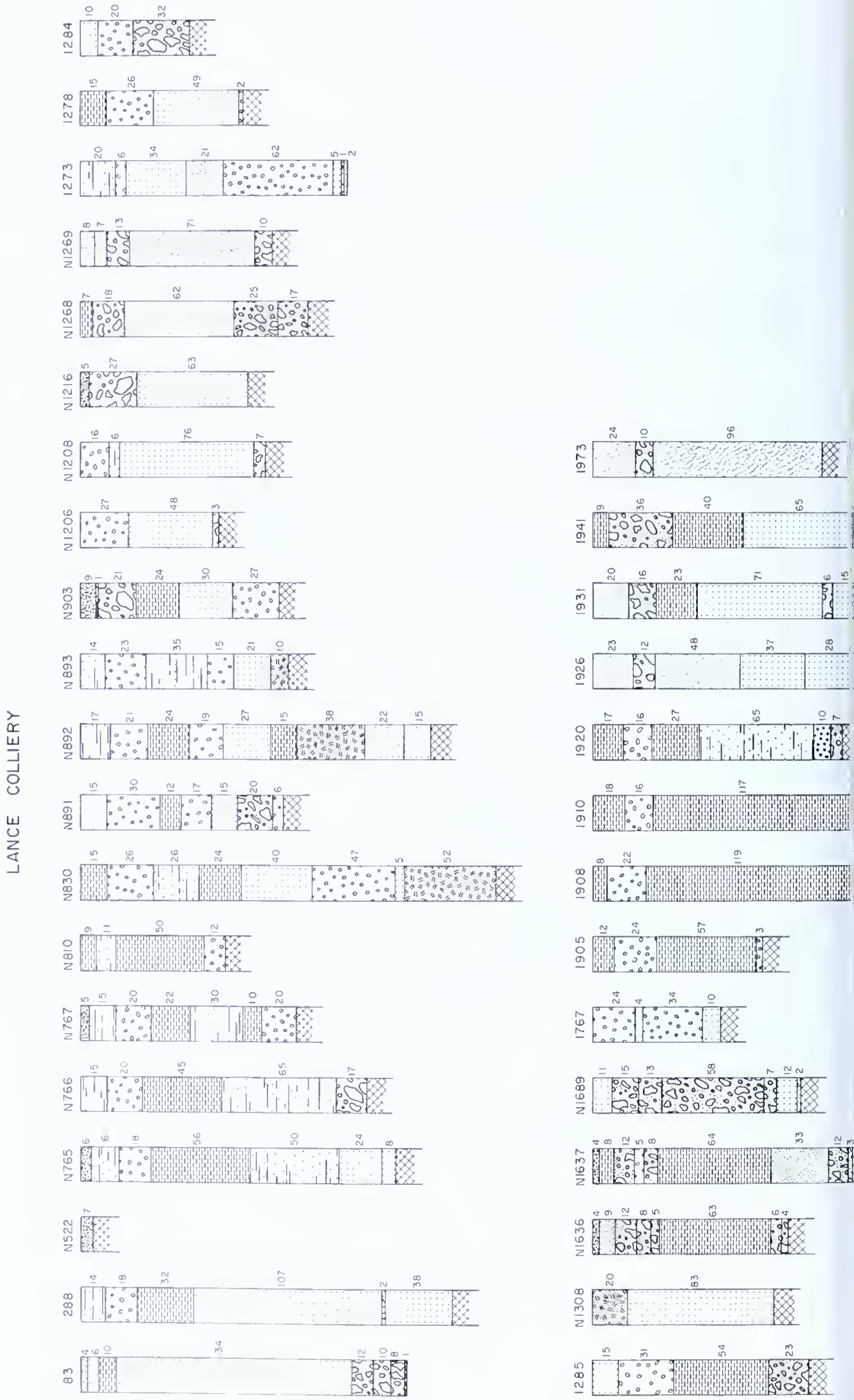
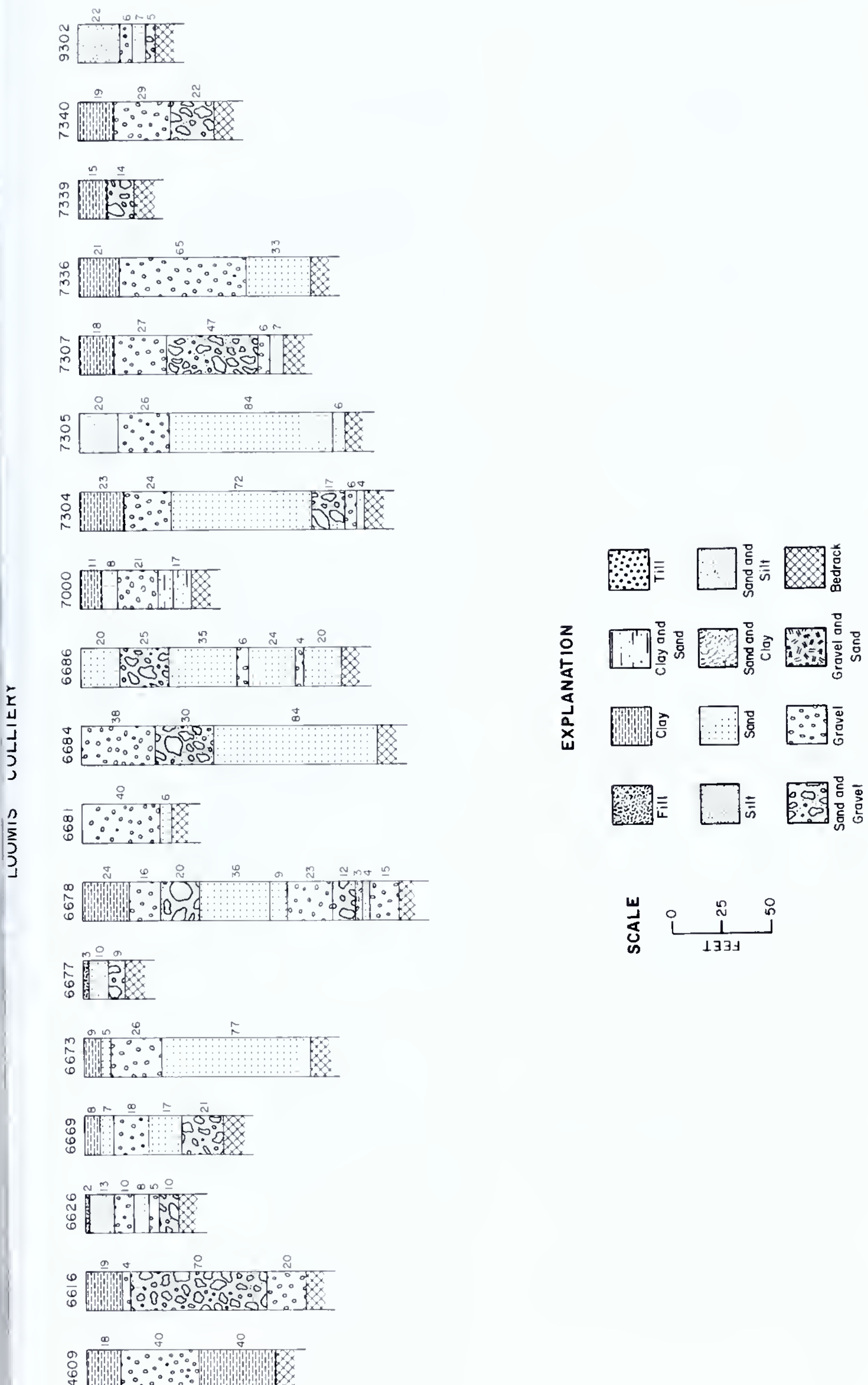
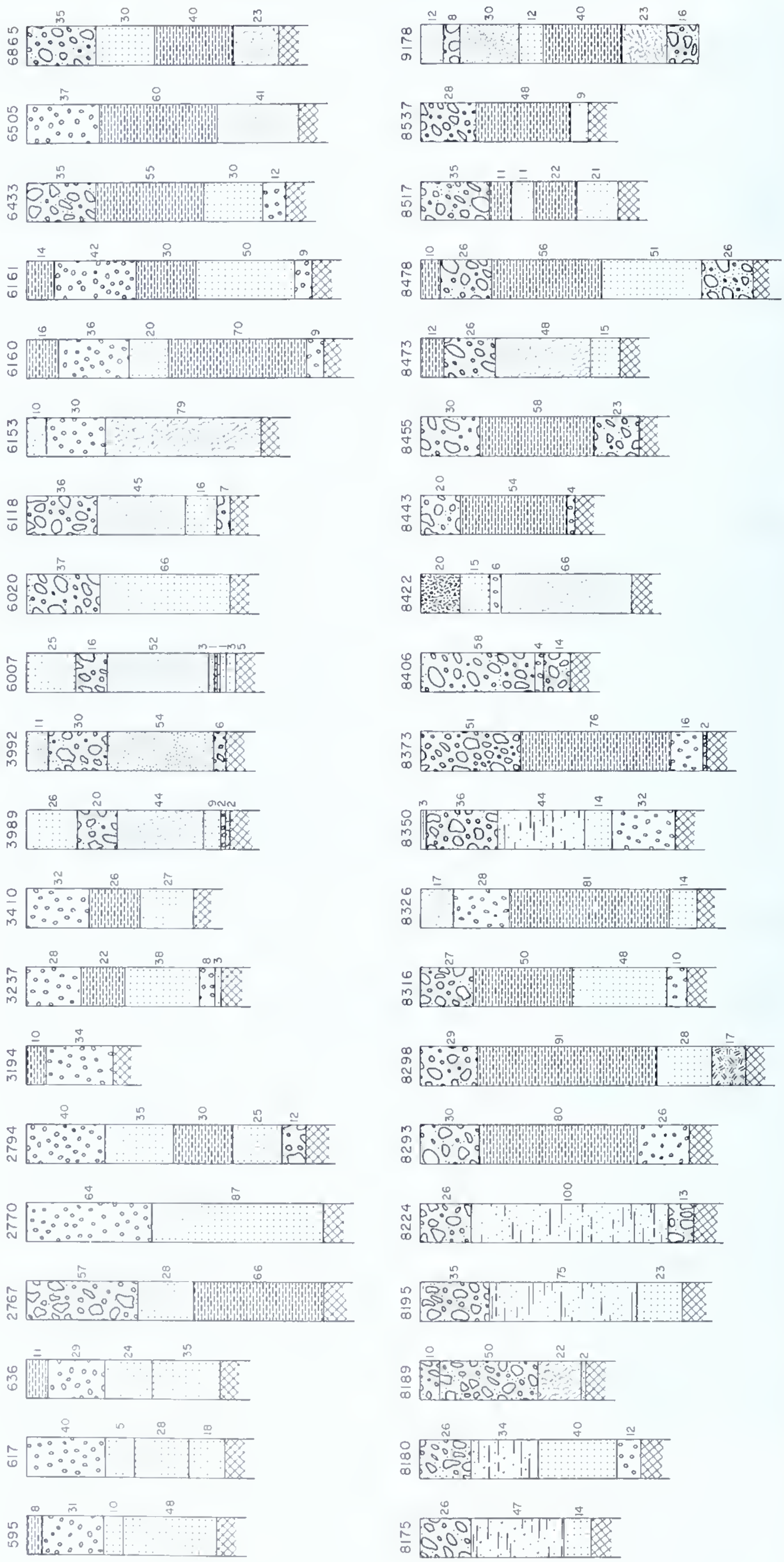
5892
5885
5879
5863
5832
5787
5765
5753

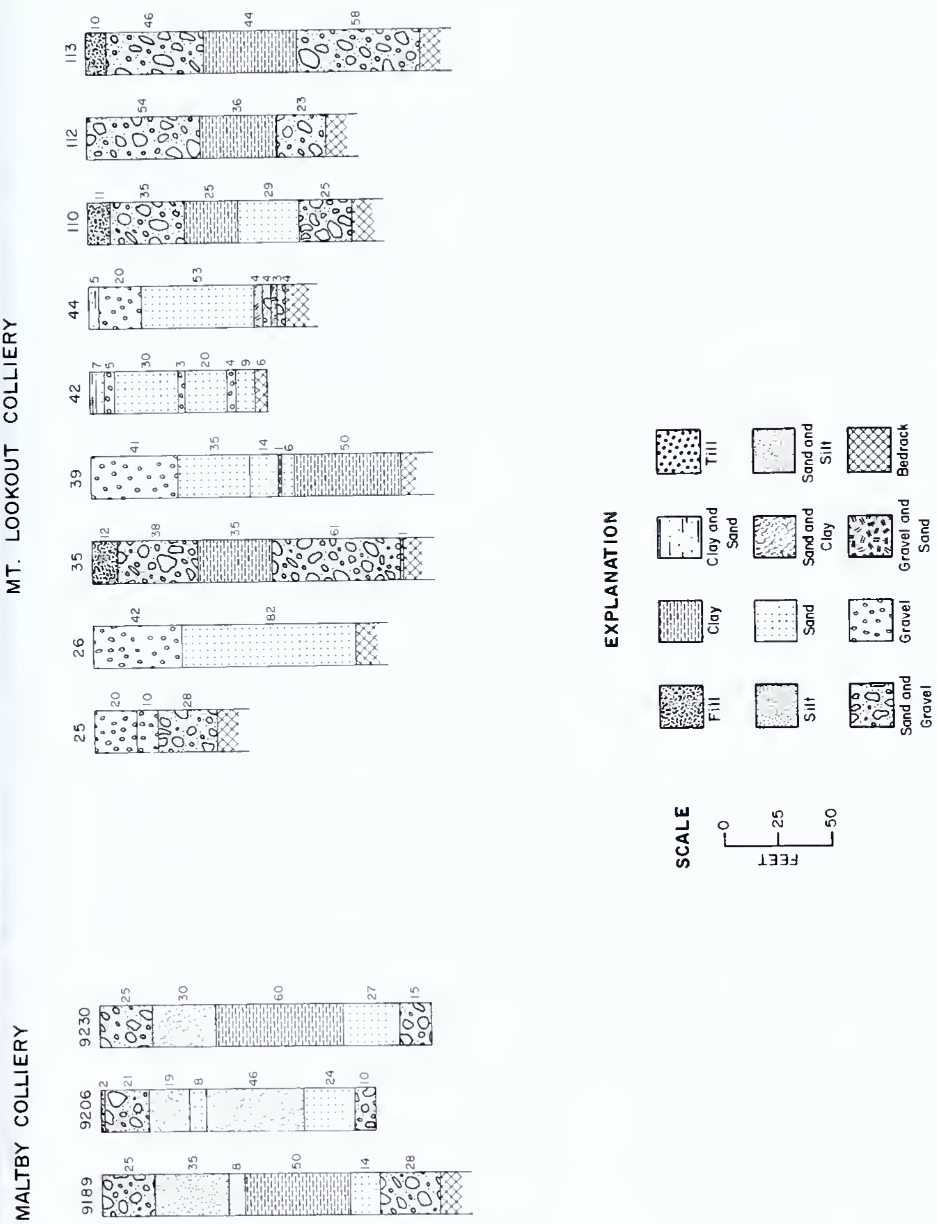

EXPLANATION
Fill
Clay
Clay and Sand
Till
Silt
Sand
Sand and Clay
Sand and Silt
Sand and Gravel
Gravel
Gravel and Sand
Bedrock
SCALE
0
25
50
FEET
HENRY–PROSPECT COLLIERIES
7782
7798
7802
7807
7808
7830
7850
KINGSTON COLLIERY
19
20
43
47
52
77
92
94
131
134
141
155
159
186
187


LANCE COLLIERY
1284
1278
1273
N1269
N1268
N1216
N1208
N1206
N903
N893
N892
N891
N830
N810
N767
N766
N765
N522
288
83
1973
1941
1931
1926
1920
1910
1908
1905
1767
N1689
N1637
N1636
N1308
1285

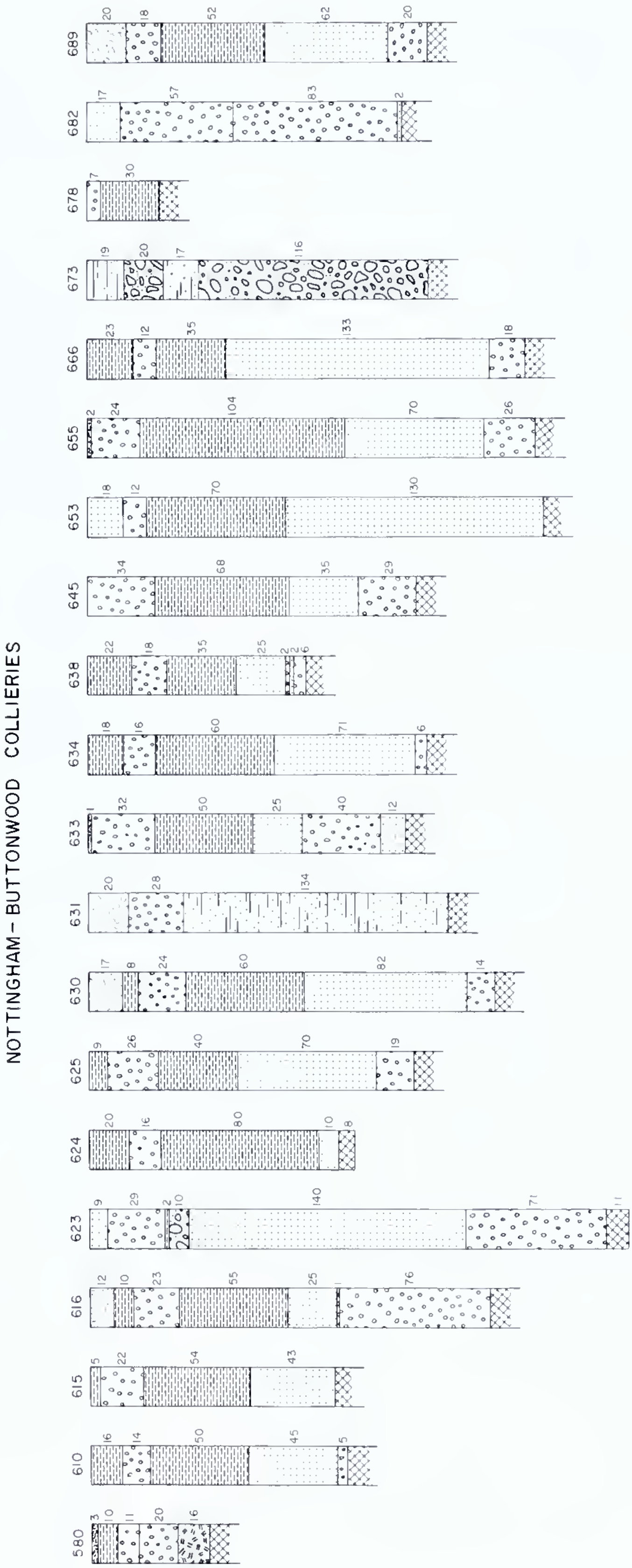

LOOMIS COLLIERY
9302
7340
7339
7336
7307
7305
7304
7000
6686
6684
6681
6678
6677
6673
6669
6626
6616
4609
EXPLANATION
Fill
Clay
Clay and Sand
Till
Silt
Sand
Sand and Clay
Sand and Silt
Sand and Gravel
Gravel
Gravel and Sand
Bedrock
SCALE
0
25
50
FEET

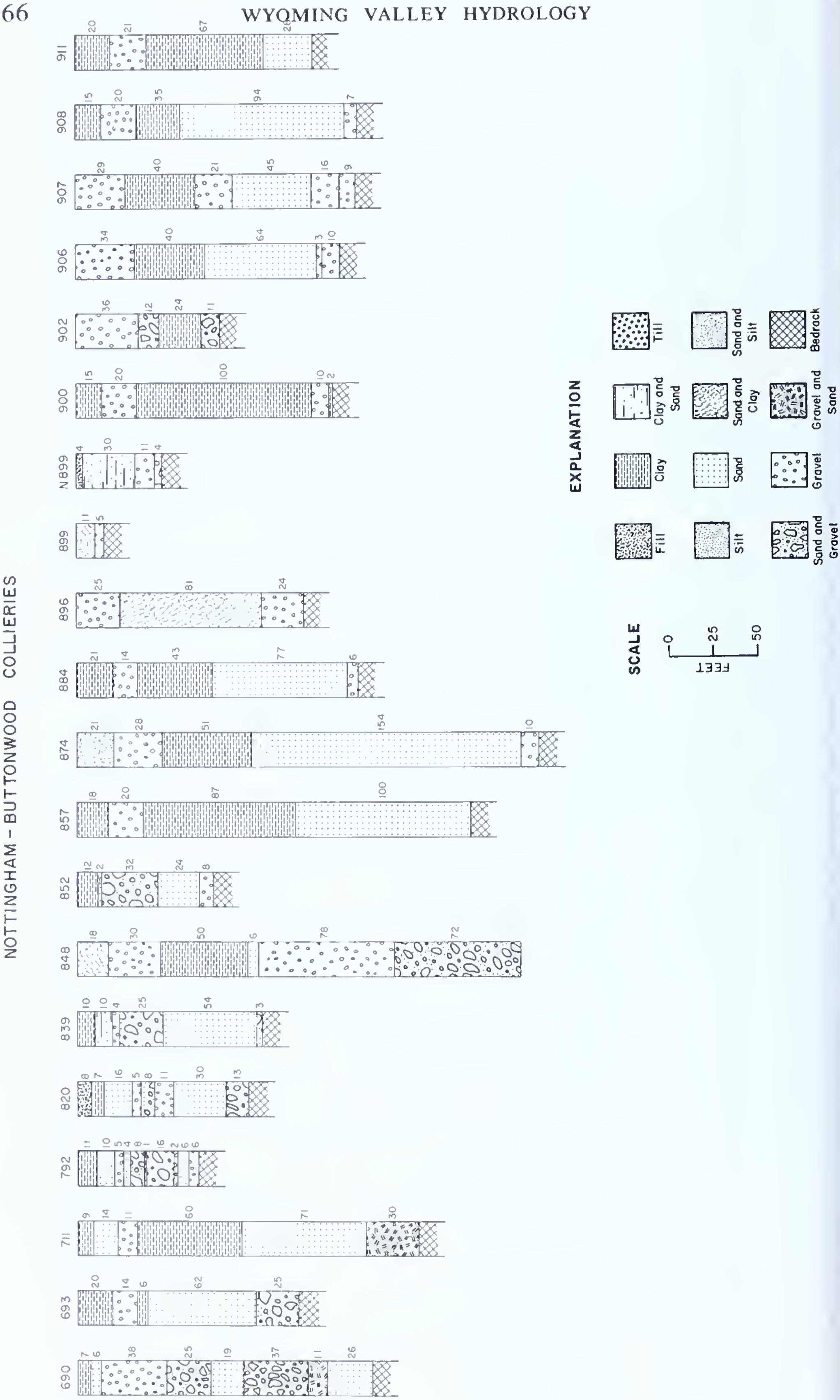


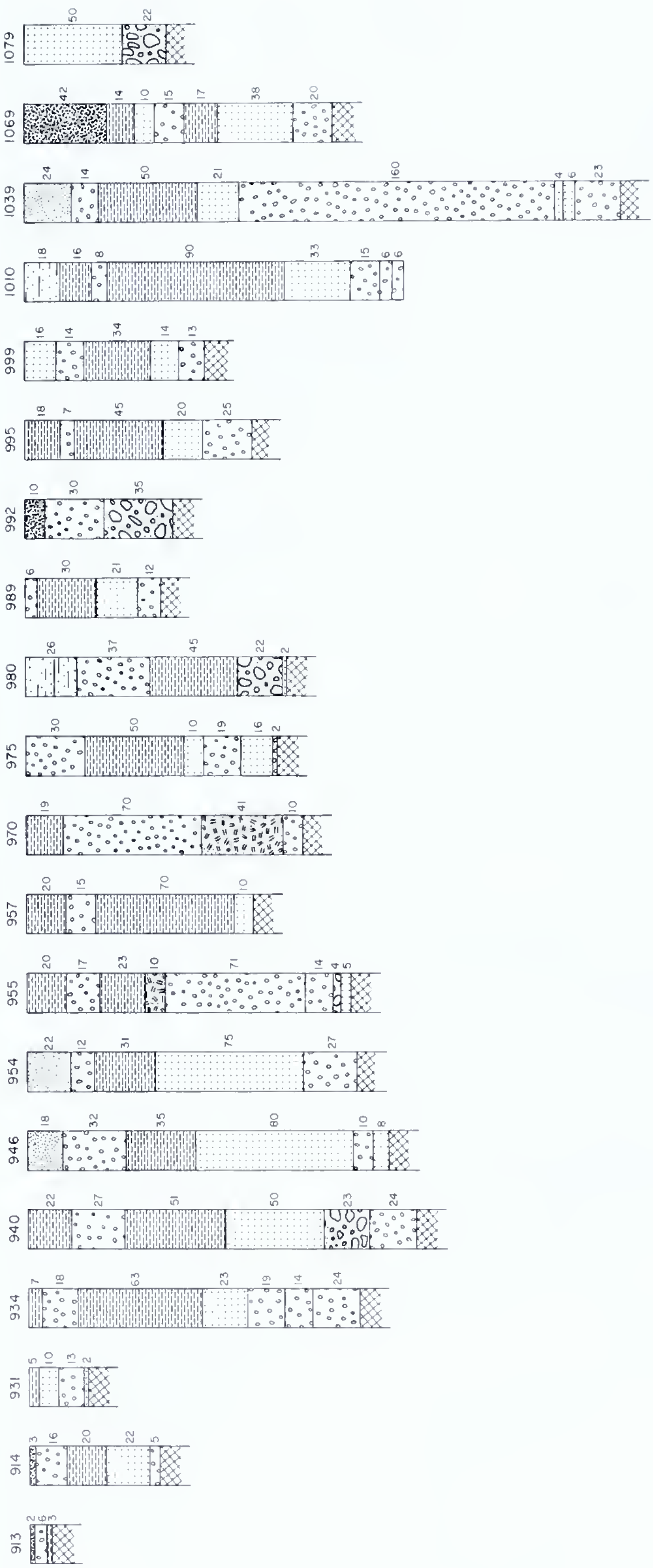
MALTBY COLLIERY


MT. LOOKOUT COLLIERY
MALTBY COLLIERY
EXPLANATION
Fill
Clay
Clay and Sand
Till
Silt
Sand
Sand and Clay
Sand and Silt
Sand and Gravel
Gravel
Gravel and Sand
Bedrock
SCALE
FEET
0
25
50

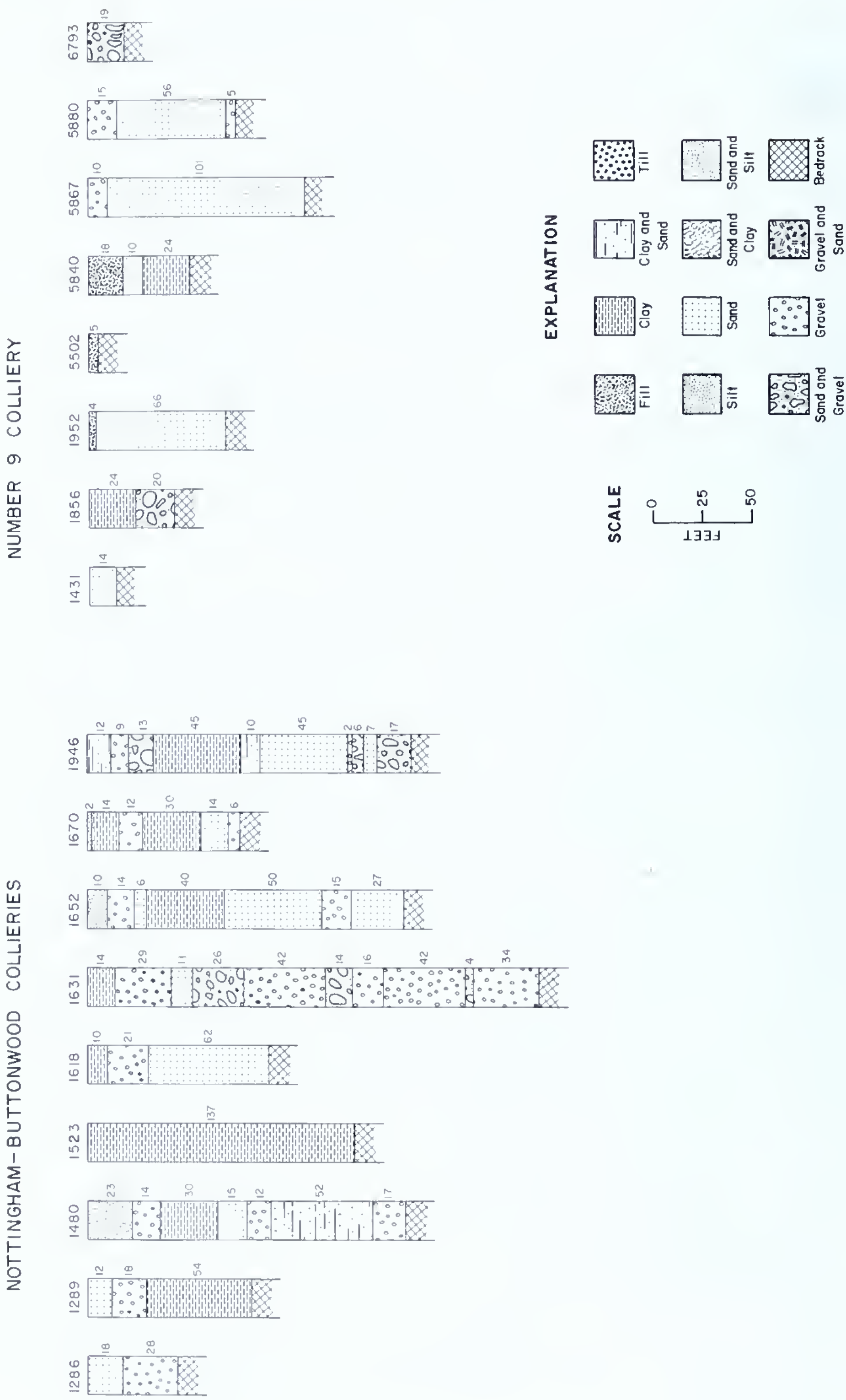

NOTTINGHAM-BUTTONWOOD COLLIERIES
573
N572
N501
N499
290
100
PCC 97
PCC 89
84
PCC 82
82
79
65
59
55
54
44
43
41
2
EXPLANATION
Till
Sand and Silt
Bedrock
Clay and Sand
Sand and Clay
Gravel and Sand
Clay
Sand
Gravel
Fill
Silt
Sand and Gravel
SCALE
0
25
50
FEET

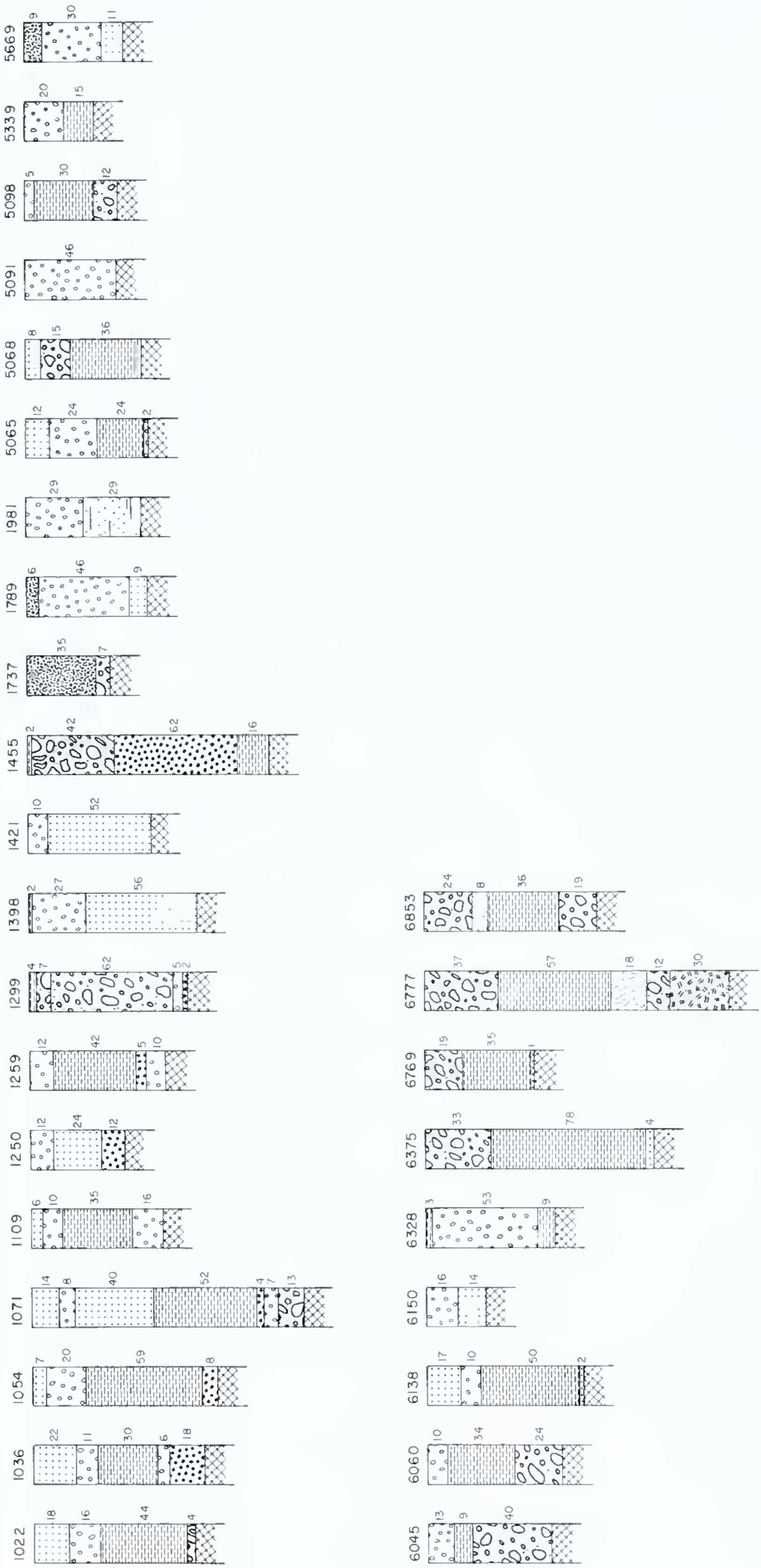

NOTTINGHAM - BUTTONWOOD COLLIERIES


NOTTINGHAM - BUTTONWOOD COLLIERIES
911
908
907
906
902
900
N899
899
896
884
874
857
852
848
839
820
792
711
693
690
EXPLANATION
Till
Sand and Silt
Bedrock
Clay and Sand
Sand and Clay
Gravel and Sand
Clay
Sand
Gravel
Fill
Silt
Sand and Gravel
SCALE
0
25
50
FEET

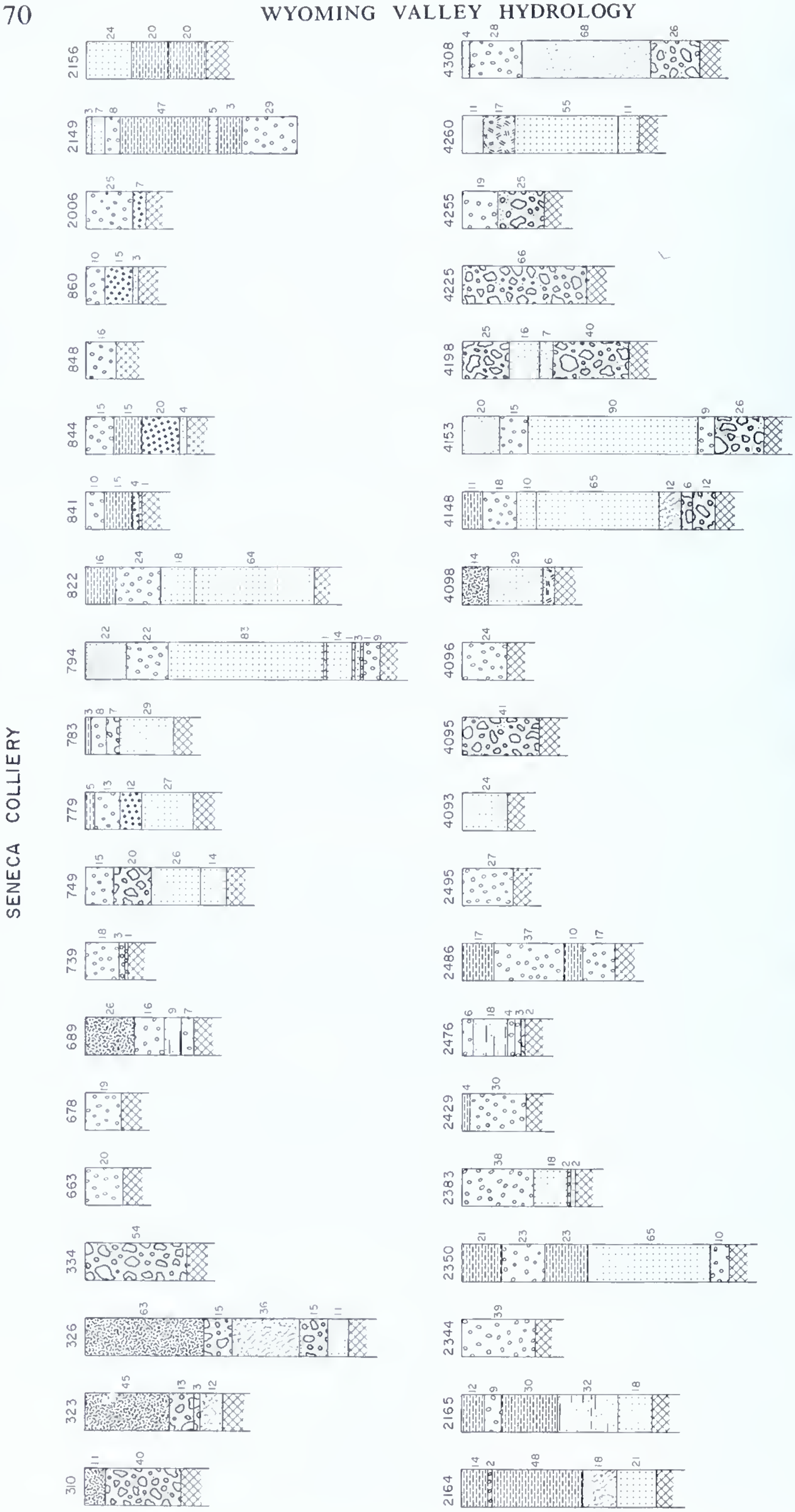


NOTTINGHAM–BUTTONWOOD COLLIERIES


NUMBER 9 COLLIERY
NOTTINGHAM–BUTTONWOOD COLLIERIES
EXPLANATION
Fill
Clay
Clay and Sand
Till
Silt
Sand
Sand and Clay
Sand and Silt
Sand and Gravel
Gravel
Gravel and Sand
Bedrock
SCALE
FEET



NUMBER 14 COLLIERY


SENECA COLLIERY
2156
2149
2006
860
848
844
841
822
794
783
779
749
739
689
678
663
334
326
323
310
4308
4260
4255
4225
4198
4153
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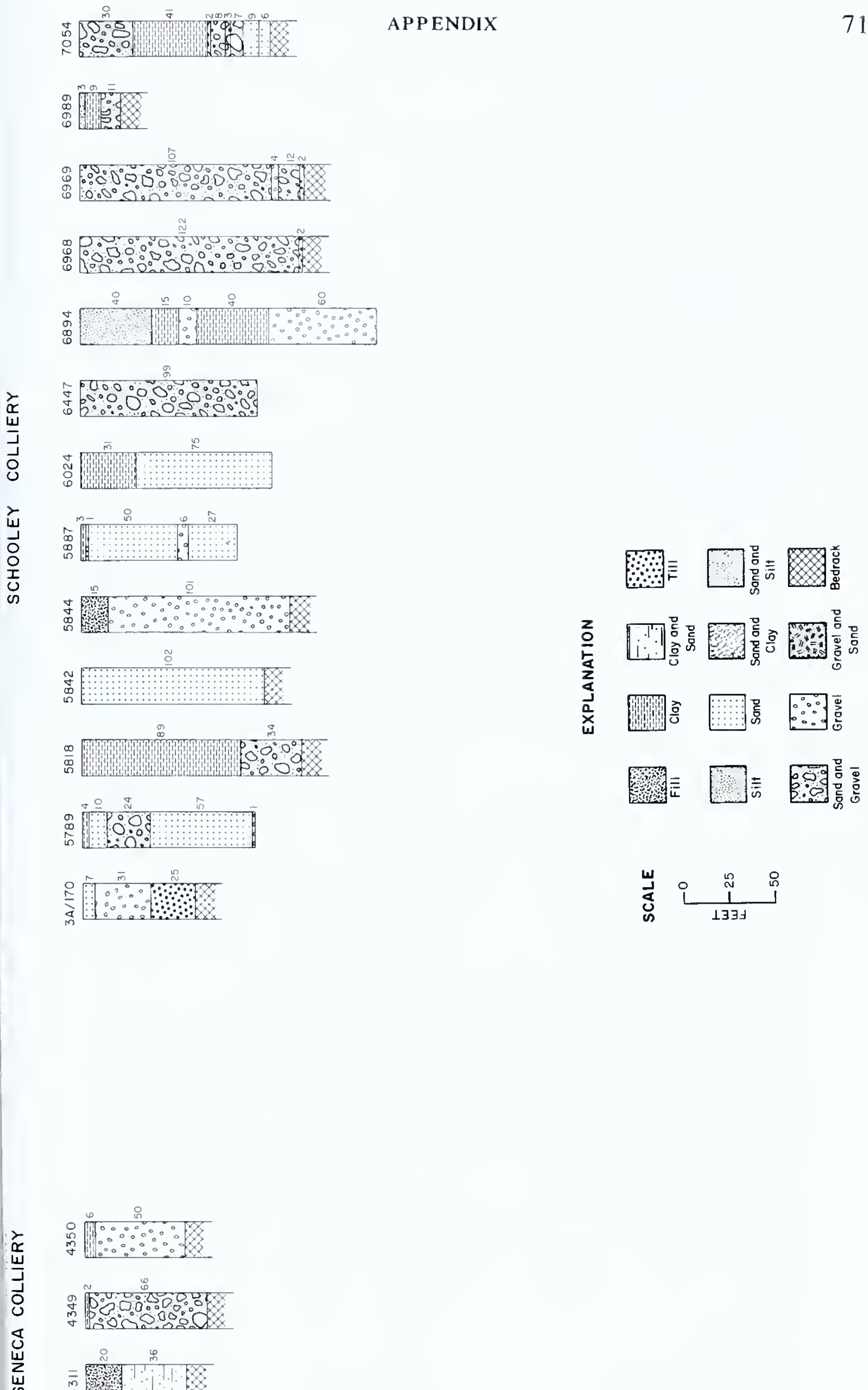
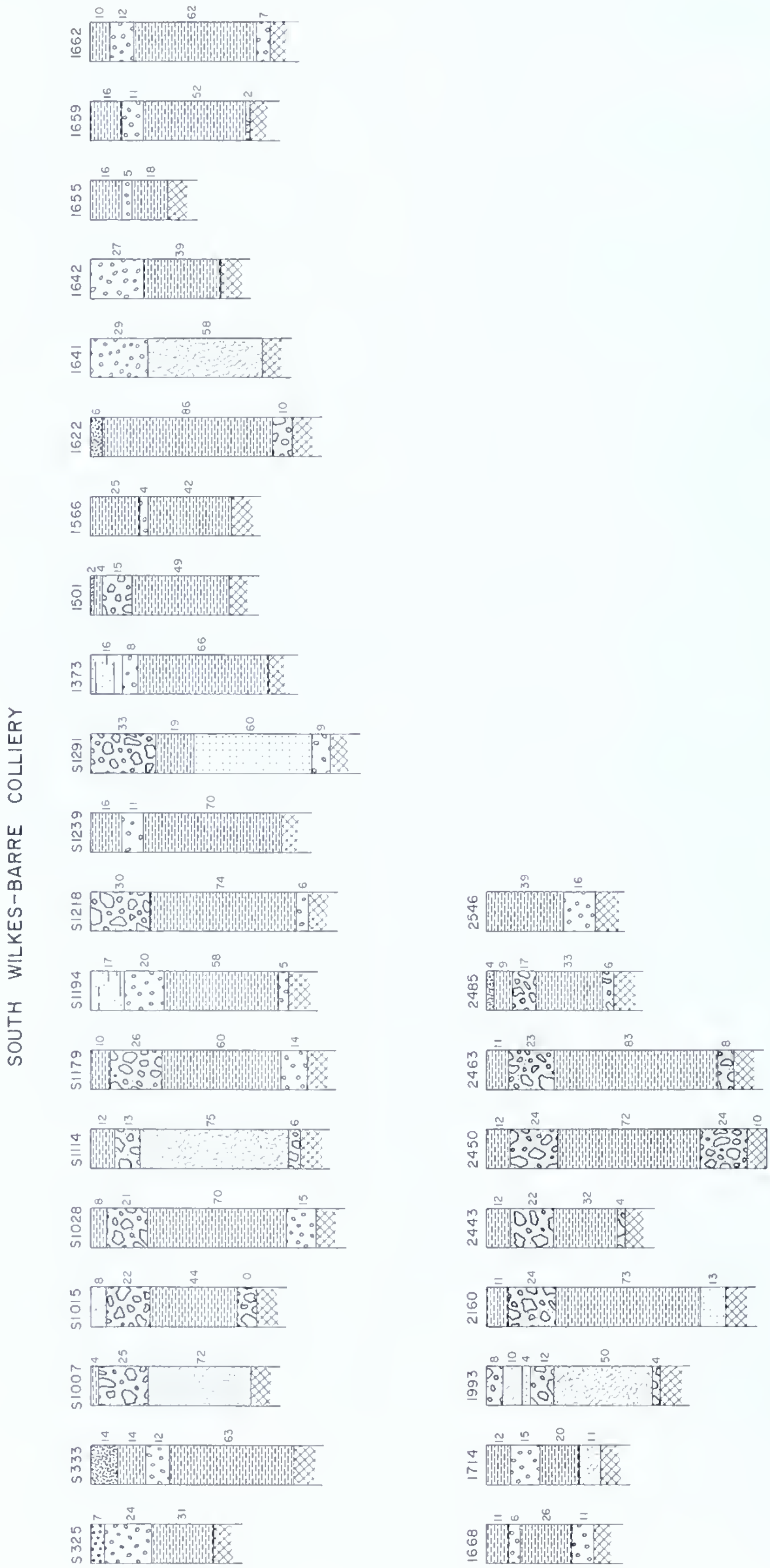
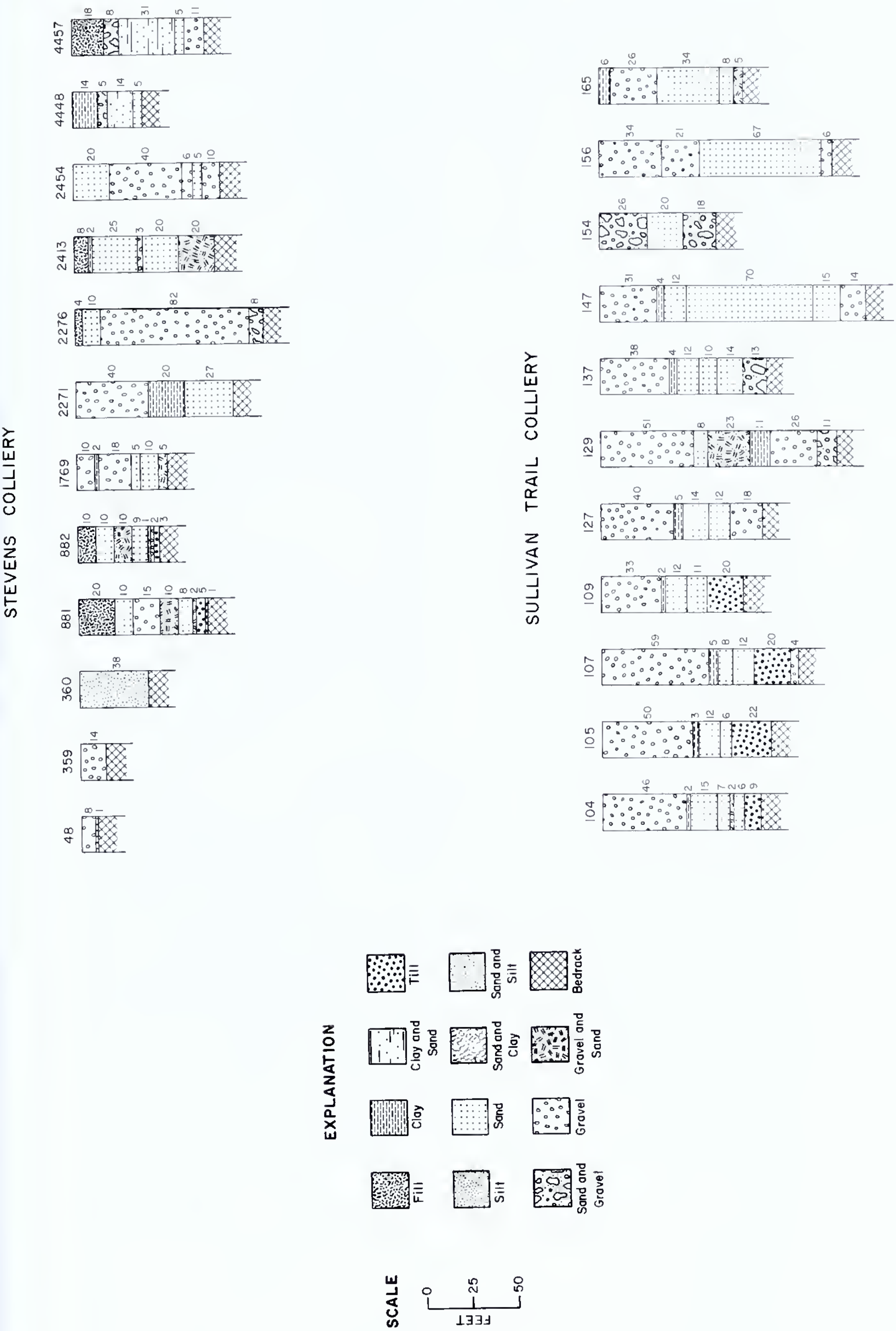
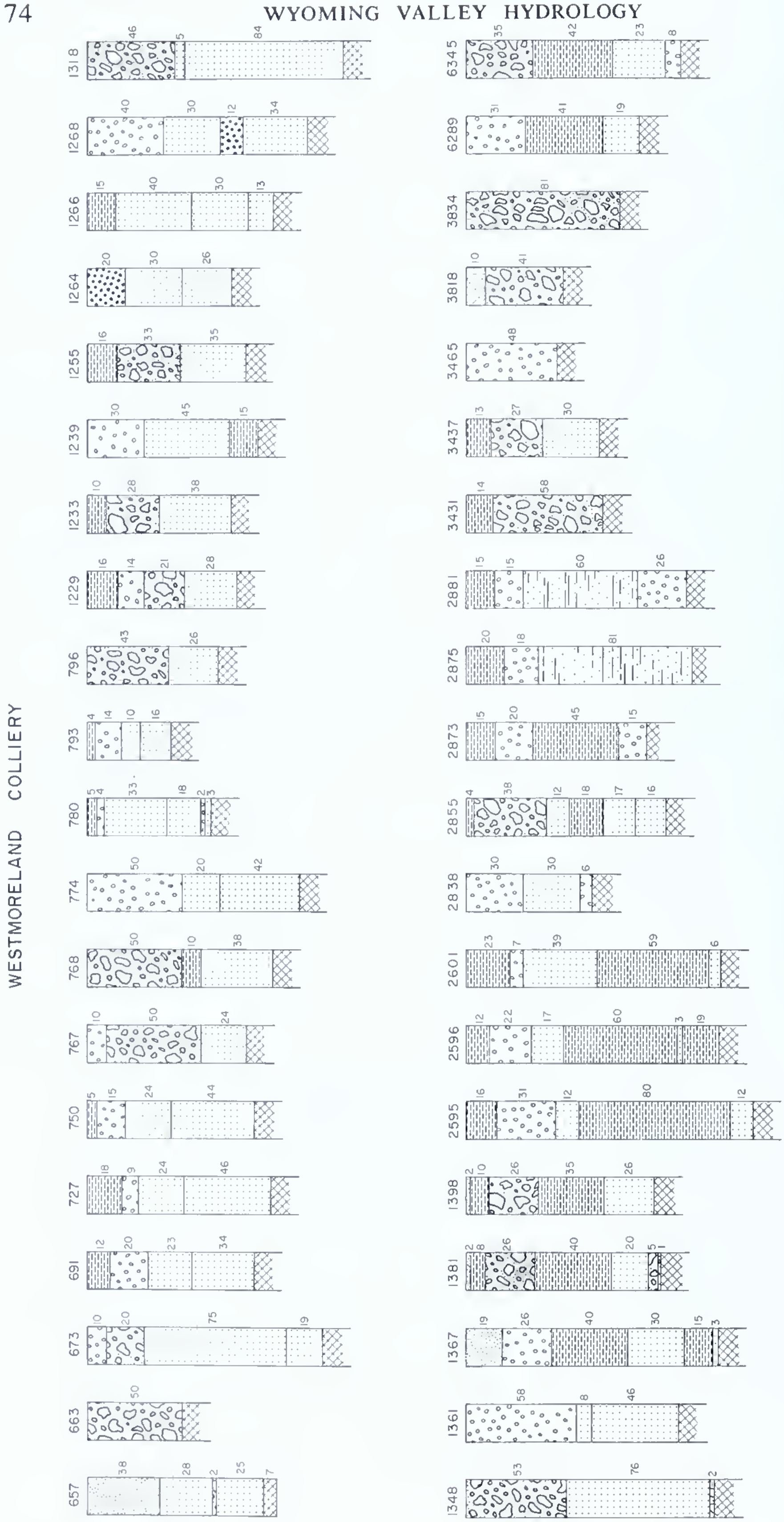
4096
4095
4093
2495
2486
2476
2429
2383
2350
2344
2165
2164

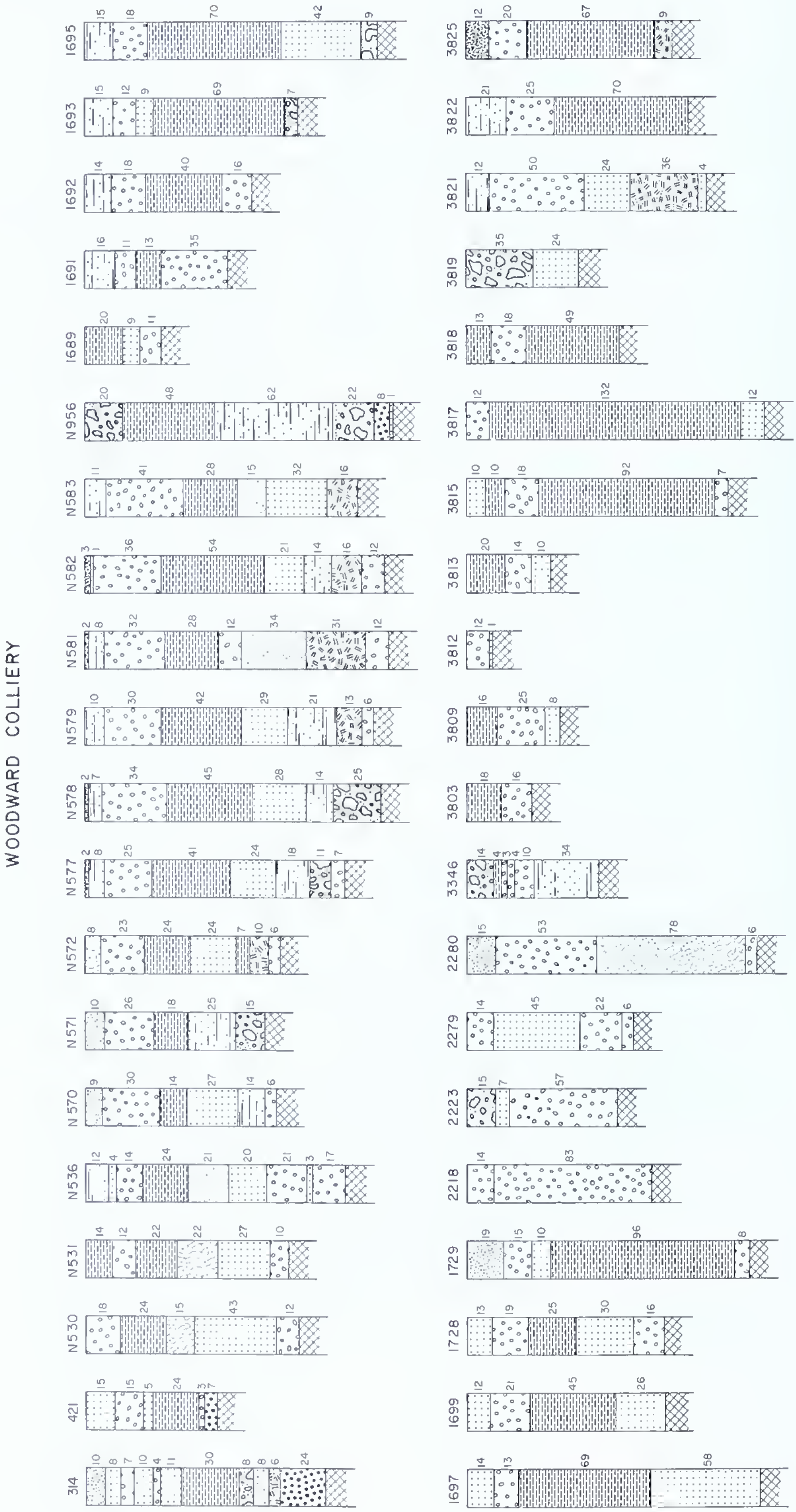

SCHOOLEY COLLIERY
SENECA COLLIERY
7054
6989
6969
6968
6894
6447
6024
5887
5844
5842
5818
5789
3A/170
4350
4349
4311
EXPLANATION
Till
Sand and Silt
Bedrock
Clay and Sand
Sand and Clay
Gravel and Sand
Clay
Sand
Gravel
Fill
Silt
Sand and Gravel
SCALE
0
25
50
FEET

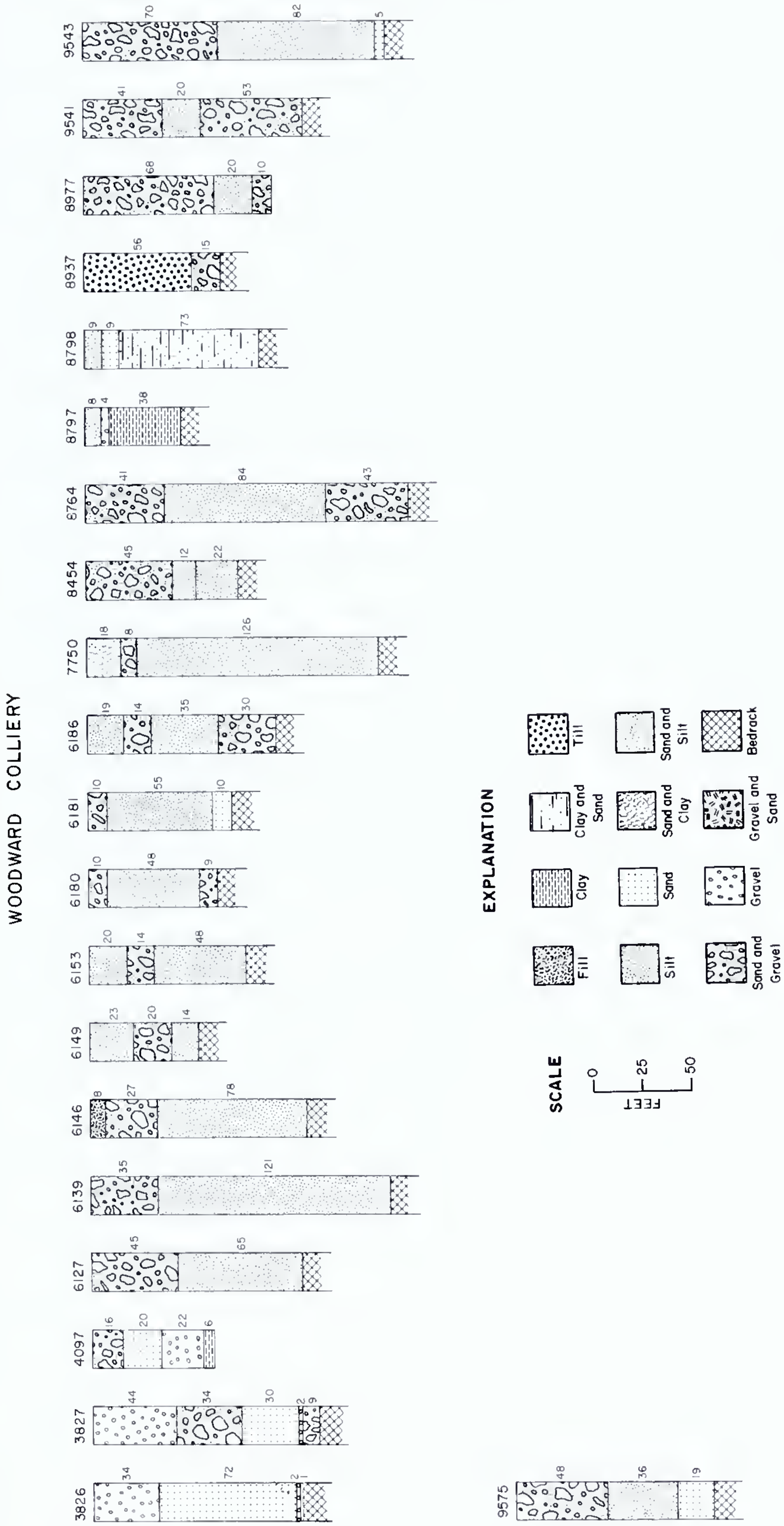

SOUTH WILKES-BARRE COLLIERY
1662
1659
1655
1642
1641
1622
1566
1501
1373
S1291
S1239
S1218
S1194
S1179
S1114
S1028
S1015
S1007
S333
S325
2546
2485
2463
2450
2443
2160
1993
1714
1668


STEVENS COLLIERY
SULLIVAN TRAIL COLLIERY
EXPLANATION
Fill
Clay
Clay and Sand
Till
Silt
Sand
Sand and Clay
Sand and Silt
Sand and Gravel
Gravel
Gravel and Sand
Bedrock
SCALE
FEET
0
25
50


WESTMORELAND COLLIERY
1318
1268
1266
1264
1255
1239
1233
1229
796
793
780
774
768
767
750
727
691
673
663
657
6345
6289
3834
3818
3465
3437
3431
2881
2875
2873
2855
2838
2601
2596
2595
1398
1381
1367
1361
1348


EXPLANATION
Till
Sand and Silt
Bedrock
Clay and Sand
Sand and Clay
Gravel and Sand
Clay
Sand
Gravel
Fill
Silt
Sand and Gravel
SCALE
0
25
50
FEET
WESTMORELAND COLLIERY
8433
8 10 47 11
8343
12 33 90
6683
11 22 46 24
6634
53 39 30 20 6
6568
33 54 28
6530
30 49 18 14


WOODWARD COLLIERY
1695
1693
1692
1691
1689
N956
N583
N582
N581
N579
N578
N577
N572
N571
N570
N536
N531
N530
421
314
3825
3822
3821
3819
3818
3817
3815
3813
3812
3809
3803
3346
2280
2279
2223
2218
1729
1728
1699
1697


WOODWARD COLLIERY
9543
9541
8977
8937
8798
8797
8764
8454
7750
6186
6181
6180
6153
6149
6146
6139
6127
4097
3827
3826
9575
EXPLANATION
Till
Sand and Silt
Bedrock
Clay and Sand
Sand and Clay
Gravel and Sand
Clay
Sand
Gravel
Fill
Silt
Sand and Gravel
SCALE
0
25
50
FEET

Topographic and Geologic Survey
Arthur A. Socolow, State Geologist

Commonwealth of Pennsylvania
Department of Environmental Resources

EXPLANATION

QUATERNARY

Holocene

Qal — Alluvial deposits

Pleistocene

Qaf — Alluvial fan deposits

Qo — Outwash deposits

Qkt — Kame Terrace deposits

Qgd — Glacial drift undifferentiated

CARBONIFEROUS — PENNSYLVANIAN

Pl — Llewellyn Formation

pPl — pre-Llewellyn Formation

mw — Mine waste

Includes silt of tailing ponds and settling basins, rock refuse of mine dumps and culm at breaker sites.

sw — Surface waste

Includes strip pits, coal piles, back fill, and quarries.

Geologic Contact

Dashed where approximately located, dotted where concealed. Hachure shows direction of dip on coal bed at base of Llewellyn Formation.

Fault

Dashed where approximately located, dotted where concealed; U—upthrown side, D—down thrown side

Contour on bedrock surface

Dashed where approximately located, Hachure shows direction of closed basin. Contour interval is 20 feet, datum is mean sea level.

A —— A'

Line of Section
(See Fig 12)

Contacts and geology modified after unpublished work of M. J. Bergin and J. F. Robertson, U. S. Geological Survey

Base map edited and published by the U.S. Geological Survey

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W28

PLATE 1. GEOLOGIC MAP OF THE WYOMING VALLEY

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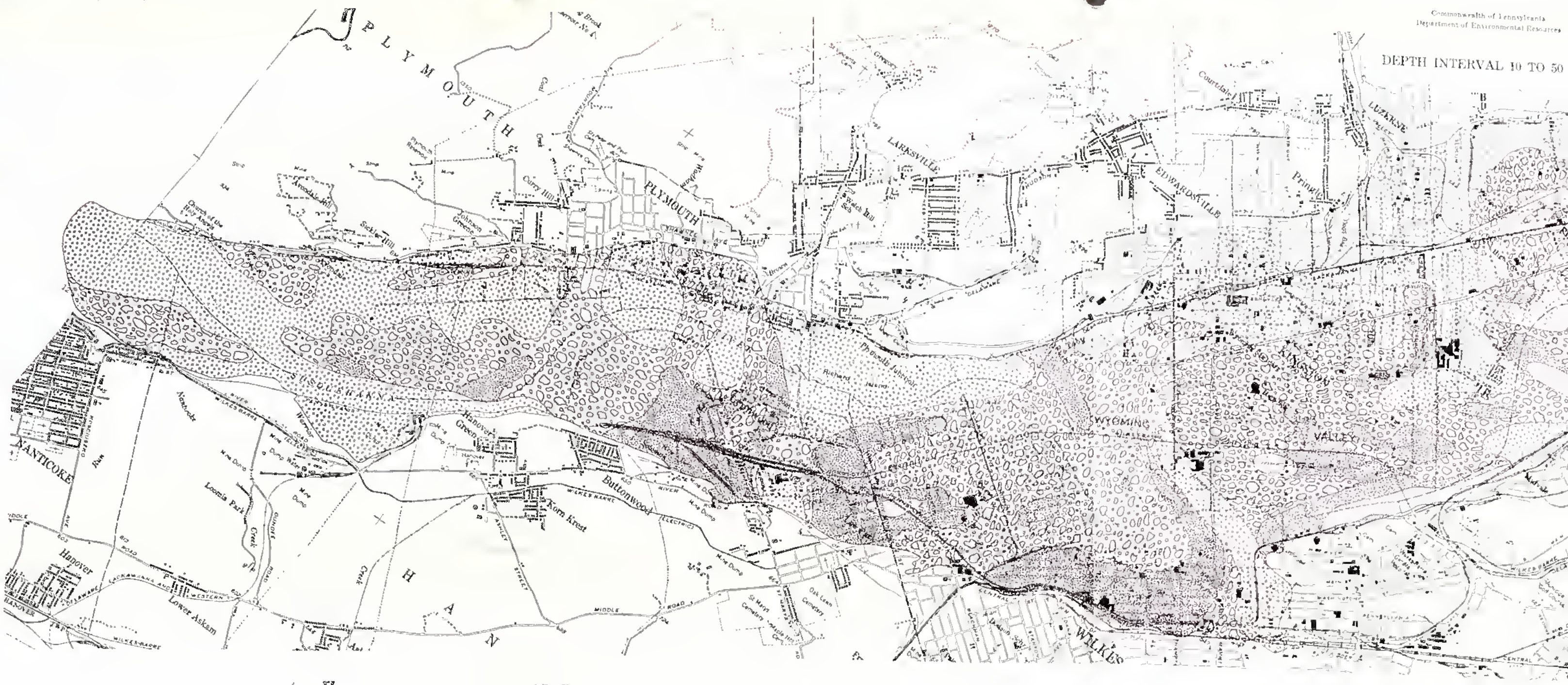
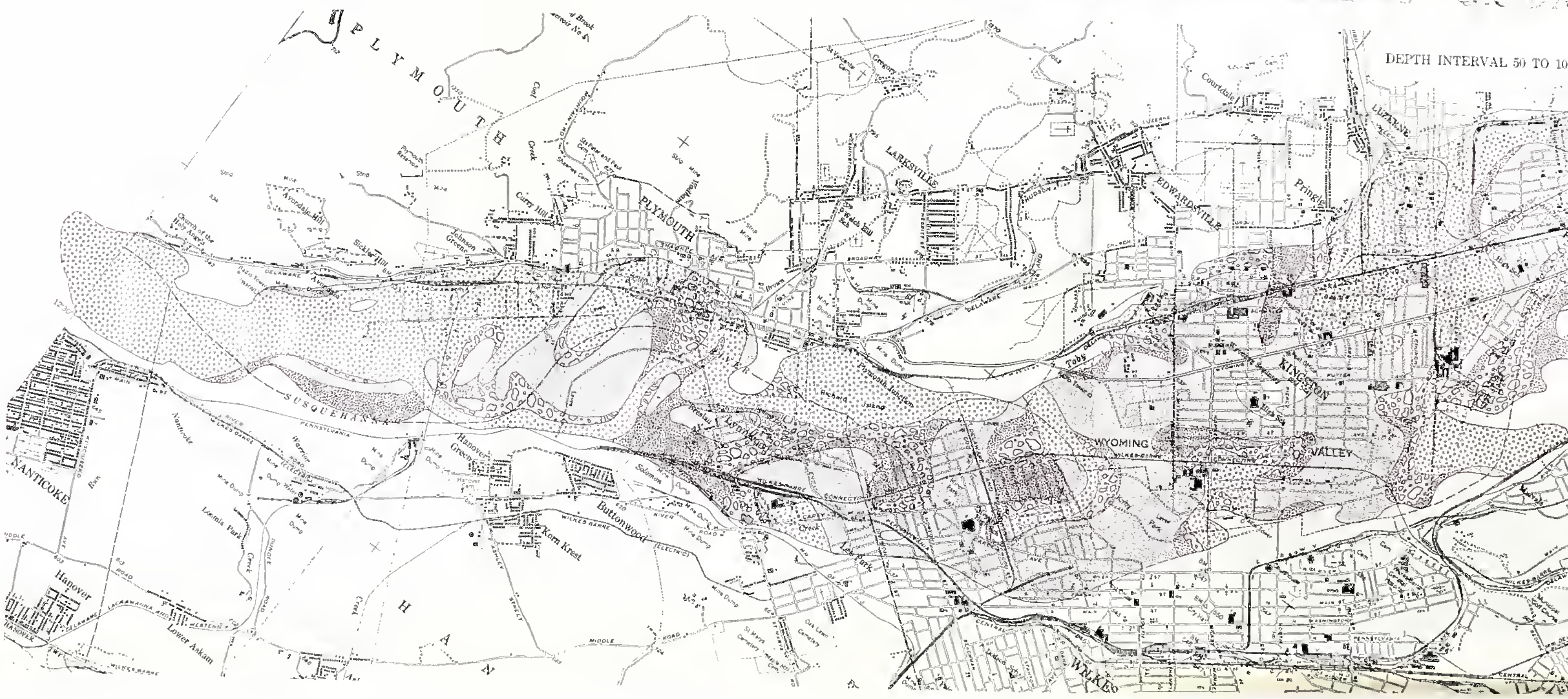
Commonwealth of Pennsylvania
Department of Environmental Resources

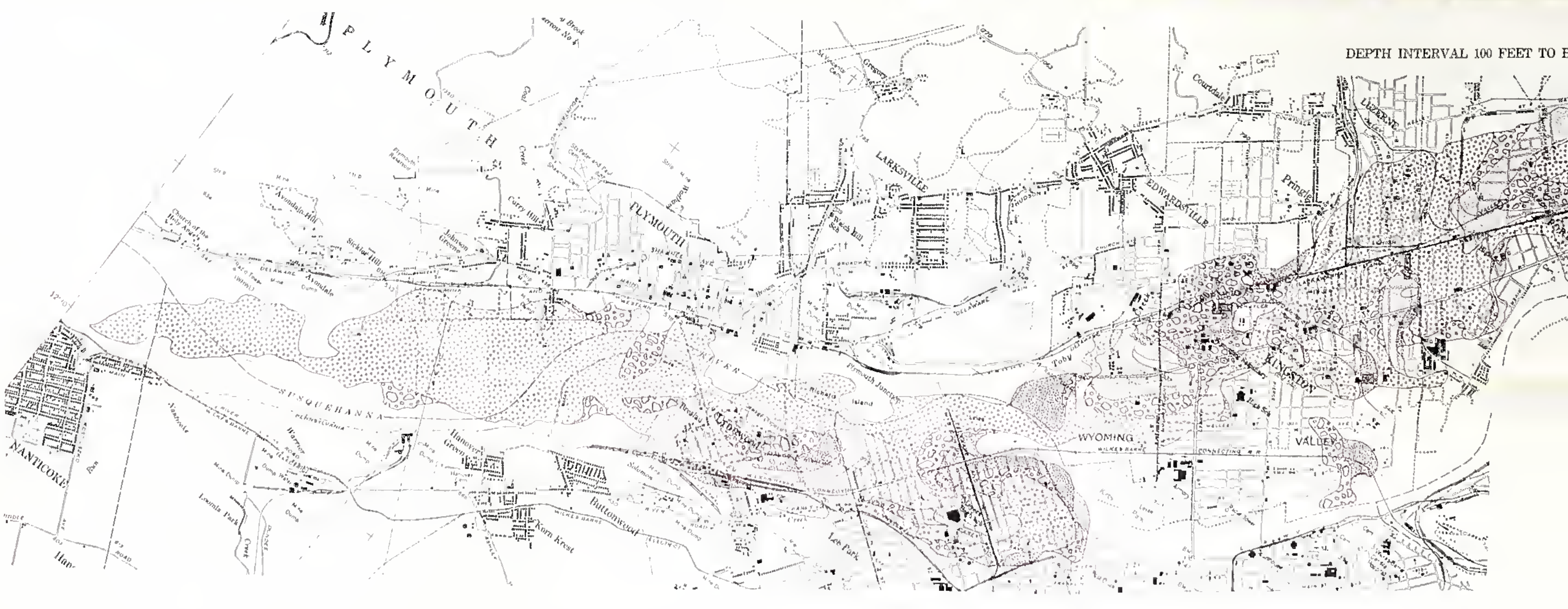
DEPTH INTERVAL 10 TO 50



DEPTH INTERVAL 50 TO 10



DEPTH INTERVAL 100 FEET TO B



SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

PLATE 2. LITHOFACIES MAPS OF THE BURI

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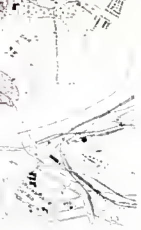
DEPTH INTERVAL 10 TO 50 FEET

DEPTH INTERVAL 50 TO 100 FEET

TH INTERVAL 100 FEET TO BEDROCK



EXPLANATION

Map Symbol	Range of Grain-Size Ratio	Dominant Grain size and Probability of Depth Interval containing water-yielding zones.
	0.25 or less	*Abundant very fine grained beds; seldom contains beds of coarse grained material suitable for obtaining ground water supplies*
	0.25 to 1	*Abundant very fine grained beds interlayed with coarse-grained beds 1 to 20 feet thick; coarse-grained beds are suitable for obtaining ground water supplies if saturated.*
	1 to 8	*Abundant coarse-grained beds that contain very fine-grained beds 1 to 6 feet thick; coarse grained beds are suitable for obtaining ground water supplies if saturated.*
	8 or greater	*Abundant coarse and very coarse grained beds that are nearly everywhere suitable for obtaining ground water supplies if saturated.*
	Bedrock	

Grain size ratio determined by:

$$\frac{\text{Thickness of sand and gravel deposits in interval}}{\text{Thickness of silt and clay deposits in interval}}$$

S MAPS OF THE BURIED VALLEY SEDIMENTS

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Department of Environmental Resources

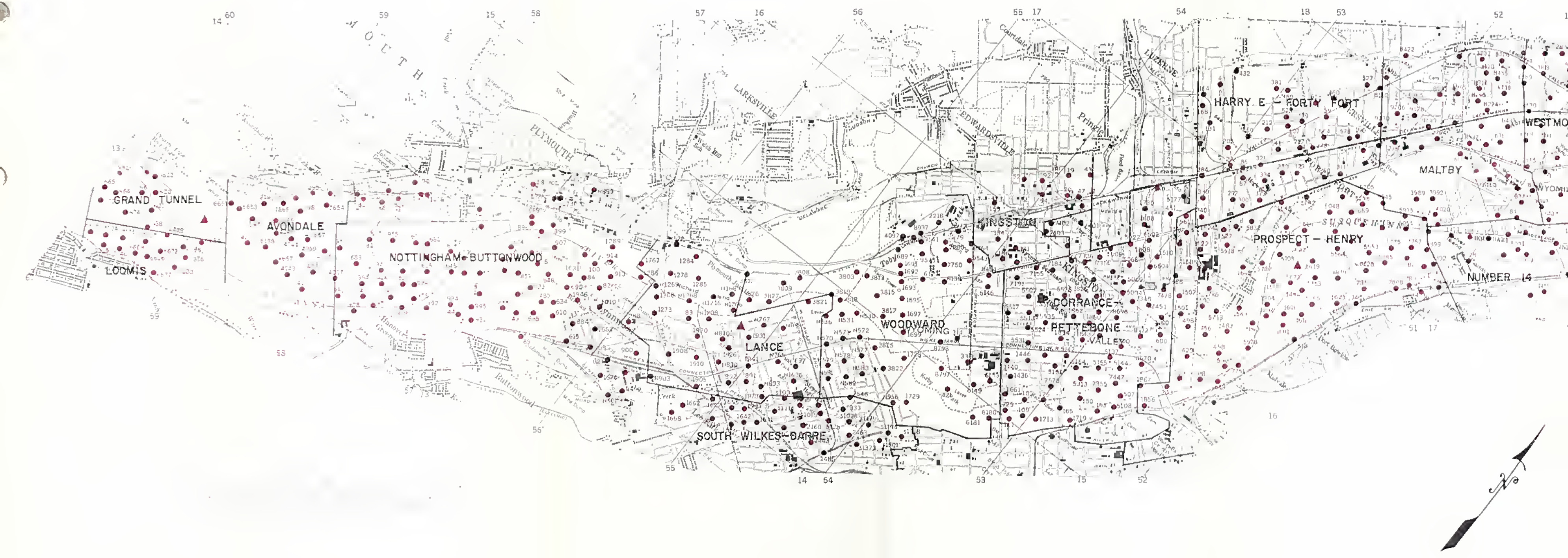
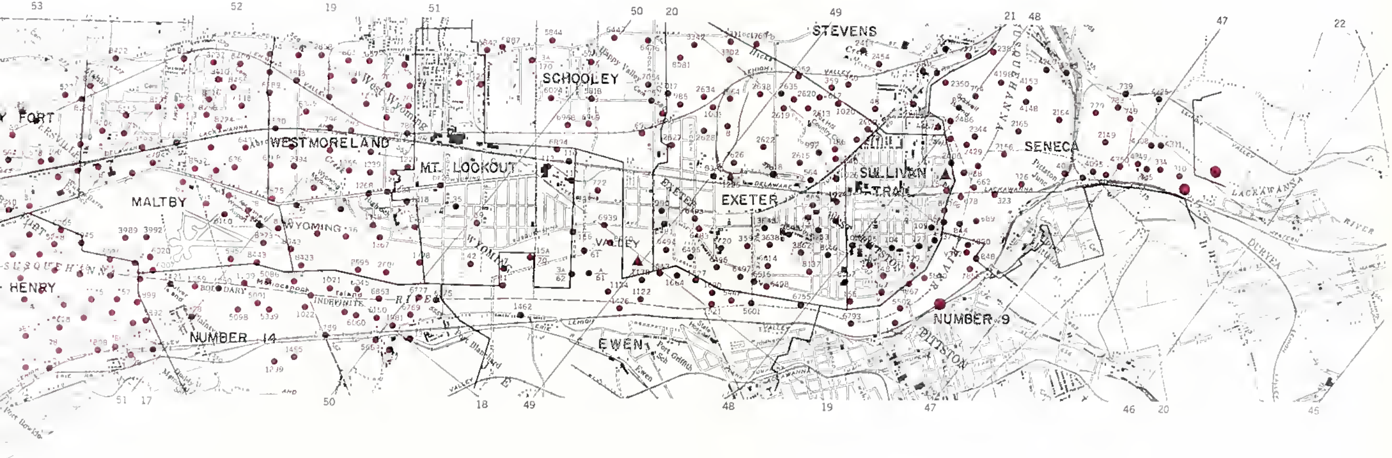
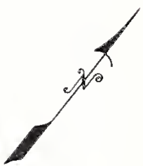


PLATE 3. MAP SHOWING LOCATIONS OF TEST BORINGS





EXPLANATION

Approximate location of property line separating mines

42 Location of boreholes and number of borehole for the individual mine

Known seepage of overflow

Areas of probable seepage

S OF TEST BORINGS

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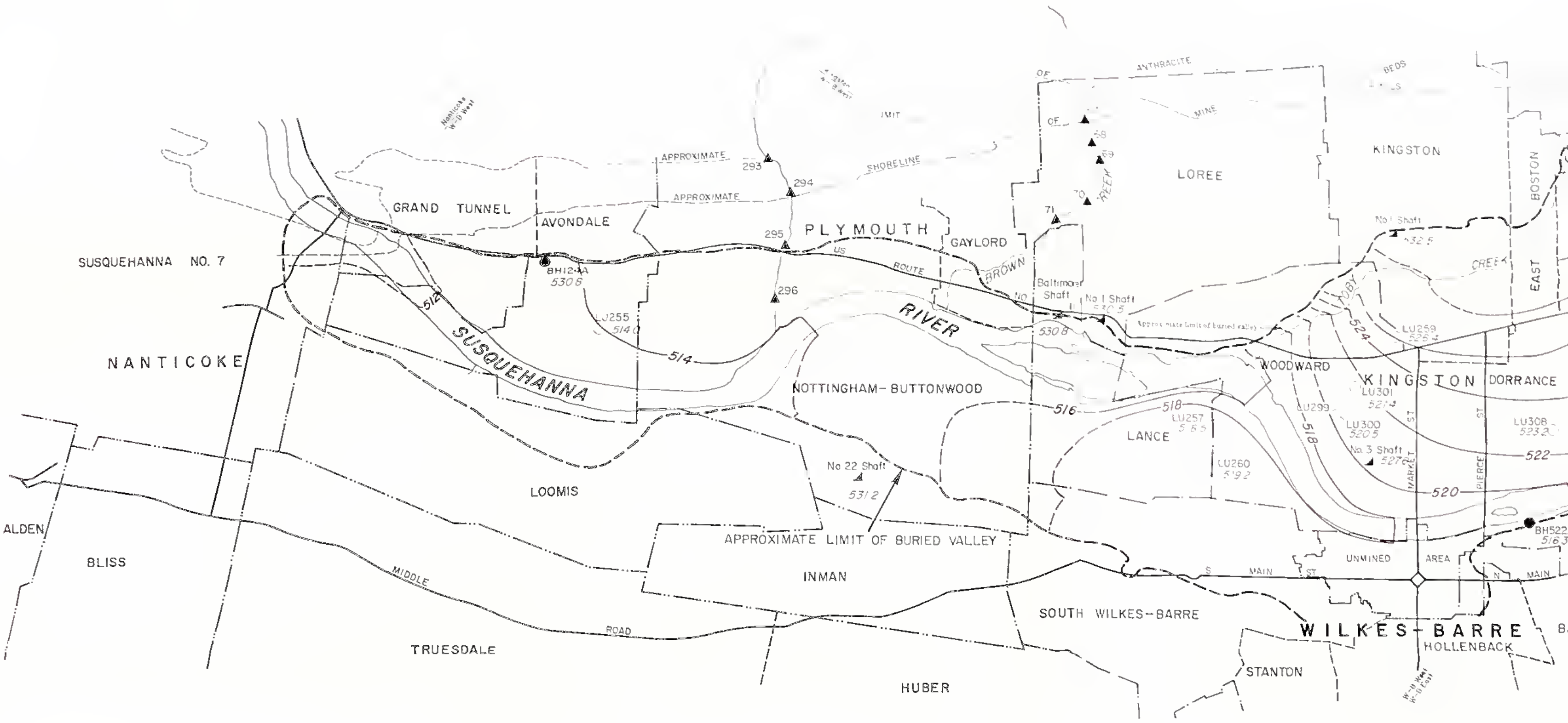


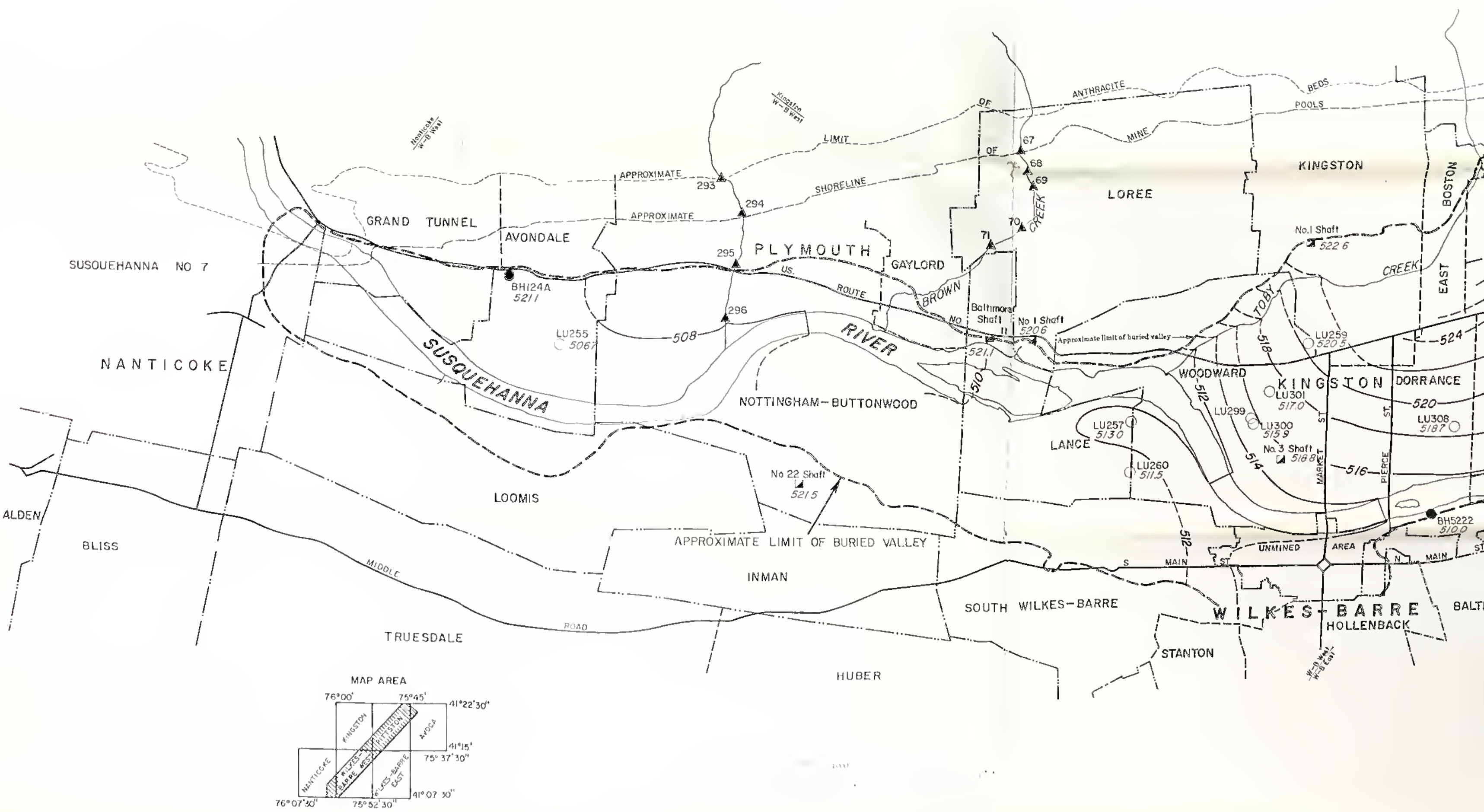
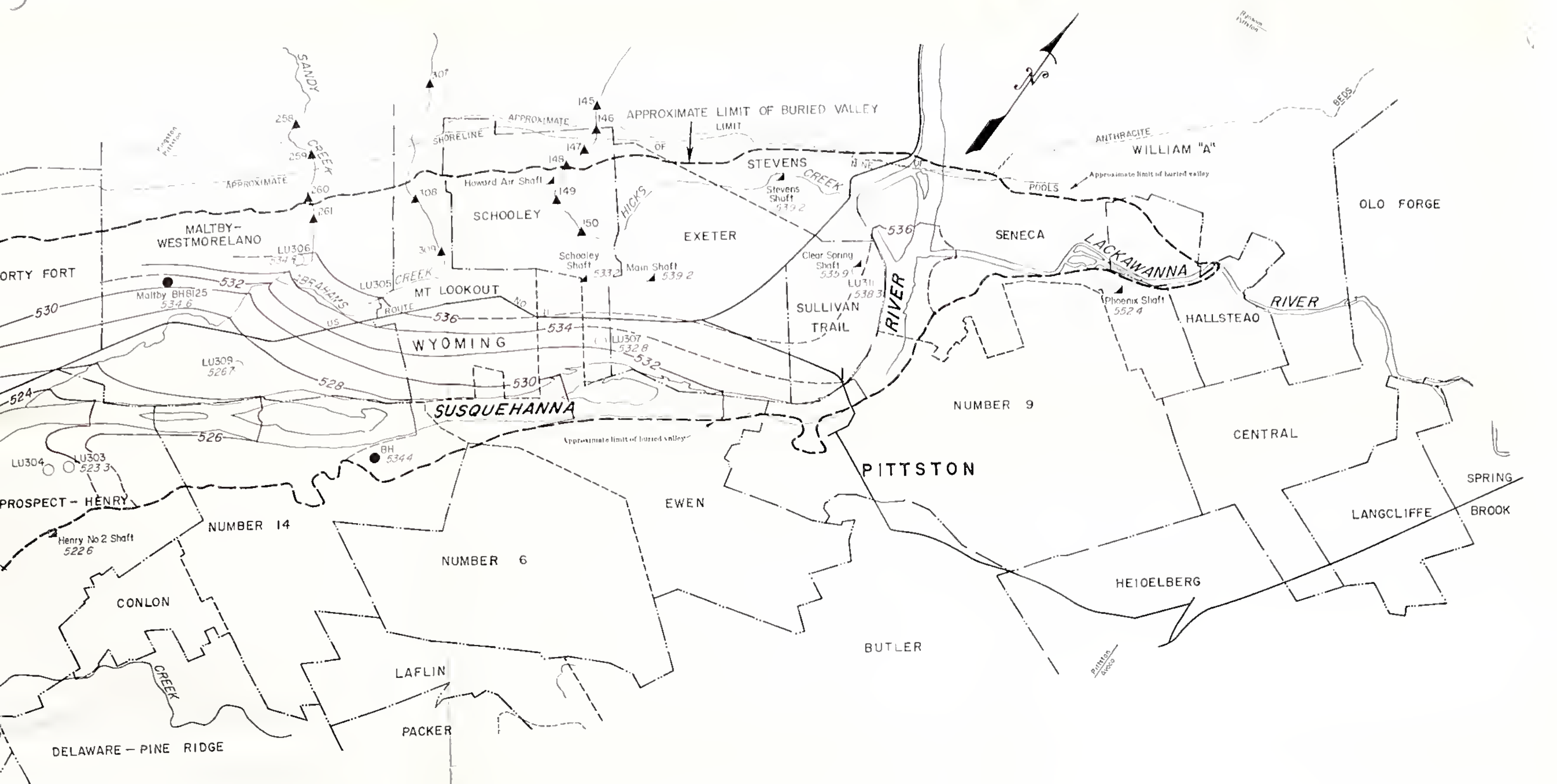
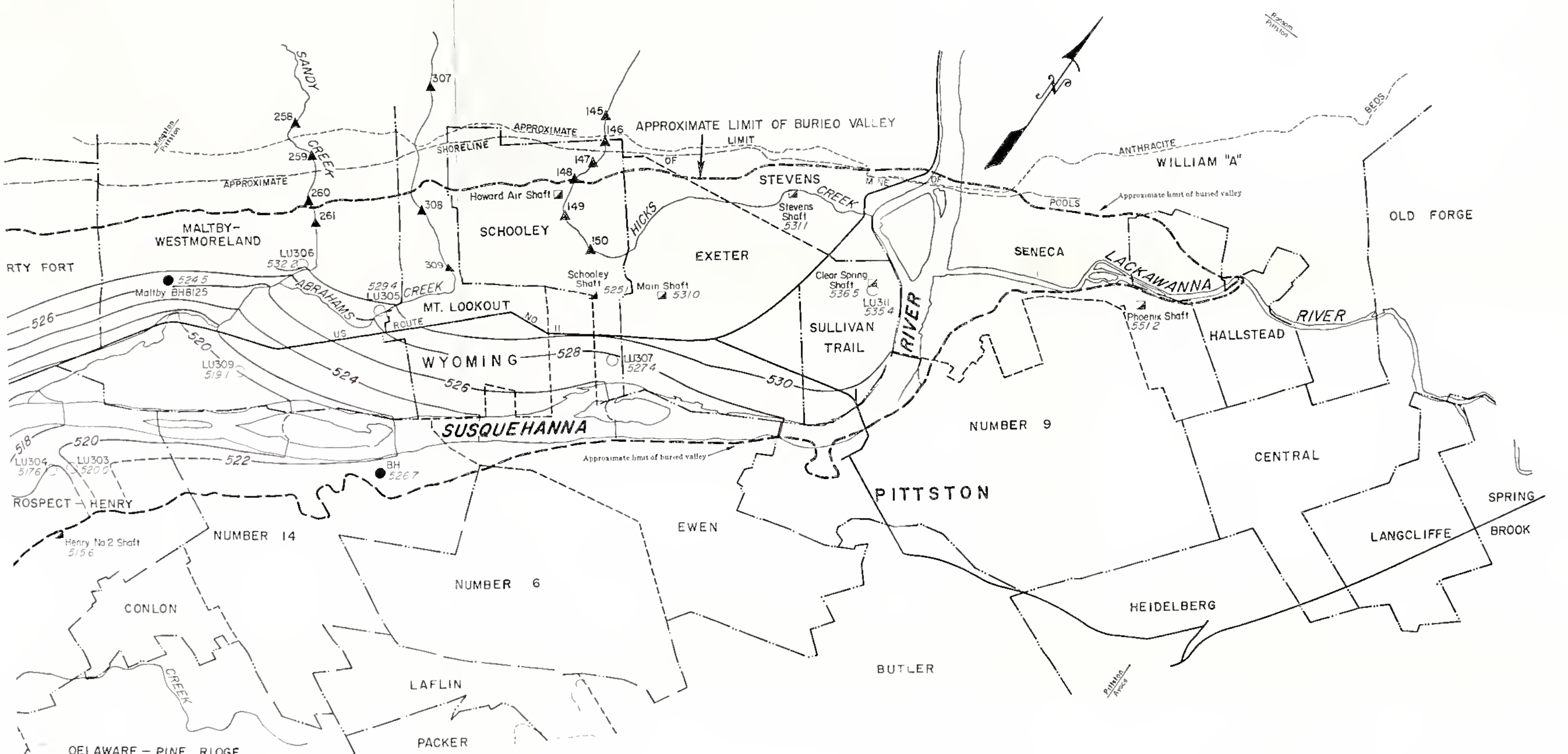
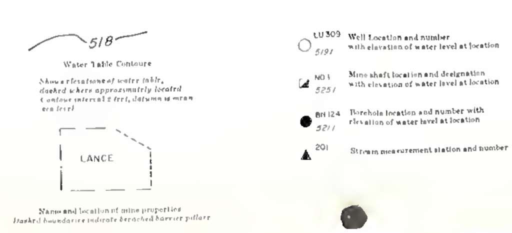


PLATE 4. HYDROLOGI
WATER TAB





EXPLANATION



IE WYOMING VALLEY SHOWING
AND MINE POOL LEVELS